Practical Mine Ventilation

J. R. Robinson

Mining

PRACTICAL
MINE VENTILATION

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MINE VENTILATION

BY

J. R. ROBINSON, M. E.

A COMPILATION of the experiences of twenty-five years as a mine-ventilating engineer and as a manufacturer of mine-ventilating fans, including the presentation and solution of many practical ventilation problems with which the author has come in contact.

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PREFACE

The author of this work has been engaged for about twenty-five years in the ventilation of mines, mostly throughout the Appalachian Coal Fields. His experience has been varied. Difficult problems have been presented to him, many of them so new and of such novel nature that considerable study and application were required for a solution. On account of this experience, he naturally has come in contact with much that is unusual and to those of less experience, his solutions of the various problems may be of benefit.

Through the efforts of Mr. J. O. Durkee, he was induced to begin this work, and has been assisted to a very great extent by Mr. Durkee; also by Mr. W. Z. Price, Prof. of Mining Engineering at Carnegie Institute of Technology, Pittsburgh, Pa.

The historical matter was largely taken from Calloway and Roy.

The formula were obtained from standard books of Physics and Chemistry.

It is the purpose of the author to pass over the elementary knowledge necessary to a complete understanding of the subject, so that his experience of a practical nature may be more fully developed in these pages.

It is hoped that the reader will pardon such omissions of elementary knowledge as he may require to understand the content of this work. He may be obliged to consult his Physics or his Chemistry, but the renewal of his acquaintance of those subjects may be beneficial to him. The purpose of the author is to put as much practical application of the science of ventilation of mines into this work as possible and leave the reader to his own devices in obtaining the underlying principles necessary to a complete understanding of the many problems illustrated.

Pittsburgh, Pa. J. R. ROBINSON.
May, 1922

INTRODUCTION

The historians tell us that nearly all the basic arts of civilization were invented and developed by our savage and barbarian ancestors long before we learned to make written records. Due to this fact, we do not know the persons who made the inventions or discoveries and rarely do we know the name of the nation or the tribe to whom we are indebted for these basic arts.

Long before we knew how to write down our impressions or record the common facts of life, long before even a written language was devised men were inventing and developing the tools, implements and devices which make our present civilization possible.

Perhaps one of the very earliest discoveries was the use of fire and the use of fire through long ages of development from savagery through barbarism to civilization has been the means of giving mankind the necessary metals to perfect his present civilization.

All metals must go through the fire to make them fit for man's uses. The smelting of the metals is so old that its very origin was certainly back in the age of barbarism.

It is quite easy now for us to see what a stupendous advantage man had over the other animals and over nature itself, when he learned to smelt the metals from the ores and make for himself from these metals, the tools and weapons he could use to subdue nature and wild beasts and finally against enemies of his own kind. To the barbarian, however, the uses of these tools and weapons and the fashioning of them was a slow process. We can hardly appreciate what a slow process it must have been.

The finding of the metals was no doubt accidental. Some barbarian likely built a fire on a ledge of rocks against a bank containing the metal ores and the metal separating from the ores due to the heat and some flux that was present, would flow into the ashes and some bright barbarian, no doubt, tried to make use of the metal thus obtained. Perhaps many ages, many generations knew of the metal before any individual was intelligent enough to fashion the find into a tool. It has been shown by the archaeologists that the metal tools that we find made by these primitive men were fashioned like the stone or flint tools that preceded them, showing the imitative qualities of the early people. But, through many generations there gradually came changes in the tools until we have those of the present time.

In the earliest times, the metals were smelted in the open with a charcoal fire and it is only in very recent years that coal was used to smelt the metals.

We are apt to think of our barbarian ancestors as though they were of little concern to us but they were the discoverers and inventors of painting of all kinds and of pottery of all kinds. They domesticated the animals that are so useful to us now. They invented navigation and brought it to a high state of perfection and all our architecture of today is but an imitation of theirs. There is one art, however, that they knew nothing about and in the present state of our civilization and the development of our mechanic arts, it is the greatest of all, mining coal. Perhaps, the mining of coal is a passing phase of our civilization.

Perhaps, as we develop the mechanic arts and learn more and more to control and manipulate the forces of nature, we will gradually replace the use of coal with other forms of power but at this time in the year of 1922, coal is the basis of all our arts and without it in great abundance, we could not carry on our present civilization. When we think of the absolute necessity of coal and its place in the arts, all right thinking people will concede the justice of giving this great industry the benefit of all mechanical inventions and modern appliances. Chief among these, to those who conduct the mining operations under the ground, is the ventilating apparatus that furnishes the fresh air to those within the mines; for ventilation is to the mine what lungs are to the individual. Without lungs the individual would soon cease to exist as would the mines without ventilation.

It is the purpose of the author to briefly review the origin of the art of coal mining before going into the special feature of ventilation and in doing this to use as many authorities as possible without quoting from their works unless necessary. The reader will bear in mind that what he is about to investigate with the author is not original but is a summary and compilation of the ideas and works of many men. No originality is claimed for this treatise. It is hoped that the subject matter presented and the manner in which it is presented will be useful to the mining industry.

CHAPTER I

RÉSUMÉ OF HISTORICAL FACTS

The word coal as we spell it now, and with its present meaning attached is of very recent origin. The root word is "kol" and is common to all the Teutonic languages of which English is a branch. This word was originally applied to what we now call Charcoal, which is the fixed carbon residue of wood that has been subjected to destructive distillation.

The substance charcoal was the original heat-producing fuel used in smelting the metals from their ores, and also, for melting, shaping and refining the various metals through heat. When charcoal, known in those early times as "kol", was superseded by the mineral deposit, the same name was applied which gradually changed to "cole" which spelling was retained to the middle of the seventeenth century when the present spelling came into general use, and has become fixed in the language.

In the languages derived from Latin, the derivatives of the word "carbo" are used. In France and Belgium the peculiar word "houille" is used in the same sense as we use the word coal. It is supposed to be derived from the Walloon word "hoie."

Although coal mining is today, the most important of all the necessary arts, it is in comparatively recent times that it has assumed such proportions. To primitive man it was much easier for him to gather wood that he needed or to cut down trees and make them into cord wood than to dig into the ground to obtain coal. It is certain that primitive men found coal and knew that it would burn, but, being always overlaid with rock and more difficult to obtain than wood, coal was a long time coming to a place of importance as a fuel.

Reference is made by some historians of the coal industry, to a limited knowledge of the ùse of coal in Britain by the Romans, but there is no knowledge of this use of coal except some ashes and bits of coal found in some ash pits. There is no knowledge of any coal-mining operations at that time. No doubt, the Britons found ledges of coal protruding from the rocks and used what was available but there is no knowledge of any extensive use that would have necessitated a coal mining industry.

We also, have some records of the use of coal in China in a period that would correspond with our seventh or eighth century but there is nothing to tell us of mining operations.

In peering back into the dark ages of history for the origin of the coal industry, we must be guarded in drawing too hasty a conclusion. There may have been mining in the past of which we know nothing, owing to the fact that records were not made of mining operations, for in that period of darkness, the historians were of the literary classes who despised all industrial matters and who thought that wars, politics and religion were the only matters that were worthy of human interest or record. If any records were made of the industrial matters they were merely incidental.

FIRST COMMERCIAL COAL MINING

The earliest records of coal mining that the writer has been able to obtain are those of English and Scottish mines.

Perhaps, mining was first developed there, and perhaps, the English and the Scotch were the first to make records of the industry. However, that may be, we have records showing that coal was in use for domestic purposes in England about 850 A. D. and this period must have been close to the time when coal came into use, for the Venerable Bede, who was a voluminous writer on many subjects, does not mention the use of coal although he lived at Jarrow on the Tyne River not far from the city that afterwards became the coal center of England. The Venerable Bede lived about the middle of the eighth century so he preceded by a century, the time when the use of coal was first recorded. New Castle was not in existence at that time. It grew to be a town under the protection of the Norman Castle at the mouth of the Tyne, and was several centuries developing into a considerable place after the time of the Venerable Bede.

COAL AN ACCIDENTAL DISCOVERY

It seems that the use of coal was a development from some accidental discovery, for the first use of coal that is of authentic record, was along the seashores of England and Scotland, where the coal cropped out and could be obtained in great abundance. About the year 1200 A. D., we find that the monks of Holyrood Abbey, near Edinburgh, received a grant to the coal lands nearby, and also a tithe of the proceeds of the harbor of Blackness on the Firth of Forth, so that at that time, there must have been some ocean traffic in coal, as well as the domestic trade in Edinburgh; in fact, the first transportation of coal was by sea, for land carriage at that time was too expensive for such a heavy and bulky material. Owing, perhaps, that coal was first transported by sea, it received the name of "Sea Coal"; and coal in general was known by that name until recent times. We still have a reminder of this in the term "Sea Coal Facing" which is simply pulverized coal used in foundries for facing the sand moulds preparatory to pouring the molten metal into the molds. The facing puts a smooth facing on the casting which makes the sand peel off the casting easily.

In England about the same time as in Scotland, namely 1200 A.D., we have some records of the coal trade, the coal being mined in the north and carried by sea to London, which was then as now, the big city. The magnitude of this trade was not known, but it must have been considerable, for we read of a lane in one of London's suburbs known as "Sea Coals Lane" from which we would assume that there were coal yards from which the coal was distributed, and there must have been very considerable trade to give the lane its name.

OPPOSITION TO THE USE OF COAL

During the early period there was much opposition to the use of coal, not only in London but in other cities of England, owing to the smoke arising from the crude manner of burning coal. We read of the kings of England prohibiting its use and fining those who used it, particularly those who used it in breweries, dyeing establishments, etc. There is a record of the use of coal in a forge on the lands of the Newminster Abbey in the north of England in 1240 A.D., but the greater use of coal was in the houses of the poor in the large towns and cities. It seems certain that coal had not come into common use in manufacturing in this early period for Macaulay tells us that even as late as 1680 A.D. the use of coal was very limited in the industries. At that time the port of London showed a traffic of more than three hundred thousand tons annually, but this was almost all used for domestic purposes and not for manufacturing.

BEGINNING OF THE COAL TRADE

In 1325 A.D. records show that coal was being carried from New Castle-on-Tyne to France, which shows the commercial aspect of the trade of that time. From that time on, there are abundant records of the traffic in coal, but there is very little information concerning the mining operations. It seems that the first operations were quarries where the coal cropped out and the overlying strata removed and the coal again laid bare, so that it could be removed. This seemed to be superseded by a shaft or pit through the overlying strata to the coal seam where a windlass was used to hoist the coal and raise and lower the miners to and from their work. Water was removed through an *adit* which was no doubt, a duct or tunnel driven through the coal or rock on a slight grade so that the water could run out of the mine through the force of gravity. When the coal seam was too deep for the water to run out, no doubt, in the early days of the industry, the deeper seams were not worked, but through long years of development the pump was applied for removing the water from the mines. The earliest record we have of the use of pumps in the English mines is at New Castle in 1649. These pumps were bucket and chain of the type used in Chaldea and Egypt five thousand years ago. They were operated by hand at first but subsequently by horses and then the steam pump came and finally at this present writing the pumps are driven by electricity. What is next, we do not know at this time, but certainly the mechanic arts will develop still farther.

EARLY METHODS OF PUMPING AND TRANSPORTATION

With the advent of the pump, even in its crude state seams of coal lying under the water level that could not have been drained by the force of gravity were made available for use, and as the coal seams that outcrop or lay near the surface were being exhausted, these deeper seams of coal could be profitably worked. The additional expense of the pumping was added to the price of the coal. The higher price being obtainable owing to the exhaustion of the more available seams. The industry for a long time was badly handicapped for transportation. Those mines along the seaboard where the coal was close to the water, could transport their coal cheaply and quickly wherever the vessels could navigate, but the coal in the interior, away from the water carriage, was more difficult to transport. We find the packing of coal on the backs of men, women and horses, giving way to wagons and tramways were about the middle of the seventeenth century, when we find tramways of wooden rails laid down for horse-drawn wagons with flanged wheels, to run upon the rails. Through the use of the tramway the hauling expense was greatly reduced. It is curious to note that some of the wagons on these tramways were occasionally propelled by sails and this method seems to have met with considerable success at the time, but later developments superseded the horse and the sails.

In the interior of the land the transportation was not so easily solved. Even as late as 1680, we are told by Macaulay, that the cost of hauling a ton by wagons over the prevailing roads between London and Birmingham was seven pounds or about $34.00 of our money and that owing to this heavy toll, a system of public roads was established for hauling freight.

Along with this system of roads came the post chaise and stage coach. The cost of hauling a ton of coal from Birmingham to London in the middle of the nineteenth century was less than one-fifteenth of the cost of hauling by wagon in the latter part of the seventeenth century. So at this early time, the coal traveled mostly by sea, owing to the low cost of freight and thus the coal seams about New Castle were developed before the seams in the inland counties.

Owing to the low cost of sea transportation, the water route appealed to the trade and a system of canals was built in England and on the continent. Also, in the United States a number of canals were built and many streams that were navigable during part of the year were canalized with locks and dams to enable them to be useful for transportation at all times of the year. These canalized streams are very useful for the transportation of coal and other bulky and heavy freight even at this time. After the canals came railroads. This is the work of the men about the coal mines of England and Scotland and this great means of transportation is a side issue of the development of coal mining although it has assumed such marvelous proportions.

DEVELOPMENT OF STEAM ENGINE RESULTED FROM COAL

The use of steam as a motive power owes its inception to the development of the coal mining industry. The first workable steam engine of which we have record, was applied by Newcomen to pumping water from a coal mine at Wolverhampton, England, in 1712 and from that time on the development of the steam engine for various purposes was rapid. It is true that this first engine was crude and did not have the necessary control or regulating and governing devices, but it was the beginning and its development to the present engine in its latest form is due to Watt, Corliss, Parsons and others, and to the general development of the mechanical arts.

As the mines became deeper, the crude windlass with man power, gave place to the gin or windlass operated by horse power and this in turn to the steam hoisting engines. I pass over the numerous devices of windmill and water power that were used both for pumping and hoisting coal as they were more of a curiosity than a practical thing at this time. The steam engine designed by Newcomen was applicable to pumping water from the mines but not for hoisting coal as it was a single acting engine, simply pushing a piston and rod one way, relying on the reaction of the water to return the piston to its original position for a repeated stroke. Watt made the engine a double acting one by applying steam to each end of the cylinder and alternately pushing and pulling the piston and rod which he accomplished by means of a crank and cam motion applied to the engine valves. The first hoisting engines, made under Watt's design, were operated in Scotland and England about 1790. From this time on the hoisting of coal was done by steam engines until very recently electric hoists have come into use.

Reference has been made to the transportation problems. They seemed to have been solved after the pumping and hoisting period. The beginnings of the modern methods of transportation within the mines began about 1780, with the introduction of cast iron rails made in short lengths and spiked to wooden rails laid length-wise of the track. The cast iron rails carried, a flange on the outside, so that a flat faced wheel without flanges on the wagon was easily guided along the track. This method proved highly successful, but when rolled iron rails were introduced the cast iron ones became obsolete and flat faced wheels gave place to flanged wheels on the wagon.

Following these improvements of transportation within the mines came the overland railway. We have abundance of history relating to this development. First railways with horses drawing the train of cars on a comparatively level track and when the hills impeded the horses, incline planes were installed to pass the train over the hills to level tracks beyond. These incline planes were sometimes operated by gravity, the loaded cars on one track hauling up the empty ones on the other and sometimes the planes were operated by steam winding engines and ropes of a type similar to the hoisting engines employed in the shaft mines for hoisting the cars from the pit.

This type of railway was employed in Scotland and England prior to 1800 but after that period, the development of the railroad was rapid and carried on by many men in many places about the same time. About this time rolled rails were introduced. They being much superior to the cast iron rails gave a new impetus to the development.

DEVELOPMENT OF THE LOCOMOTIVE

The locomotive now begins to make its appearance. The first of these engines was patented in Britain in 1802 by Trevithick and Vivian. The inventors attempted to use it first on the public roads. So that, it might be termed a forerunner of our automobile but it was a dismal failure on the public roads and this failure did much to discourage the inventors. They were not at this time, completely discouraged for they turned their invention to the coal mines. At Merthyre Tydvil in Wales in 1804 they tried their locomotive on a tramway but it was unsuccessful there also. It was a single cylinder engine equipped with a heavy flywheel. The flywheel being intended to carry over the load while the crank was passing the center and this flywheel added so much weight in proportion to the engine that the locomotive could haul very little load in addition to itself. This second failure completely discouraged Trevithick for when he was called upon to try out his locomotive in 1809 by Mr. Blackett at Wylam Colliery near New Castle, he refused to participate and seems to have dropped out of the development of the locomotive.

The next important improvement of the locomotive was made by John Blenkinsop in 1811. This improvement consisted in using two engines to propel the locomotive and connecting them to the same crank shaft, having the cranks at right angles. This is, no doubt, the most important idea in the mechanics of the locomotive for from this time on the locomotive was a decided success and it was a matter of working out the details.

Blenkinsop, however, did not succeed with his engine, to the extent of making it a universal type for he caused his transmission of power to go through a rack rail which necessitated a slow motion and while it made the engine powerful to haul a load, the machine was hampered too badly for speed to make it a universal machine. The speed of the trains hauled by Blenkinsop's engines was about four miles an hour which of course, was entirely too slow, for general use.

The impetus given to the transportation projects under way at the time by the engine of Blenkinsop should not be lost sight of by the more brilliant successes that followed, for it was assuredly the idea of the twin engines operating on a single crank shaft that made the locomotive a success and the successful working out of the minor details that followed have been given undue importance. The Blenkinsop engine was taken up by George Stephenson and adapted to the railway then in operation at Killingsworth near New Castle in 1814. His engine consisted of a wrought iron boiler with internal fire tubes and two engines connected by gears to smooth faced driving wheels. In using the smooth faced driving wheels, he got around Blenkinsop's patents. But this evasion was what made the Stephenson locomotive successful where Blenkinsop's failed for here was the means of practically unlimited speed as it was understood at that time. This engine was geared to the driving wheels and was limited to a speed of about five miles an hour but later the gearing was abandoned and the connecting rods of the engine placed on the driving wheels and cranks of the engine. Through those details of improvement the locomotive was adapted to almost any desirable speed and the subsequent railroad engineer must adapt his road bed to the grade on which the smooth faced driving wheels of the locomotive could draw the required load.

George Stephenson and his son Robert, so perfected the locomotive in its details that when it was applied to the commercial railroad between Manchester and Liverpool in 1832, the "Rocket", Stephenson's locomotive became the prevailing type and while it has been modified, improved and enlarged, the essential features of the steam locomotive are today what they were in this early type known as the "Rocket."

The locomotive is regarded today as the symbol of power, and it is justly regarded as the forerunner of our type of modern civilization but we must not forget that while it is applied to all forms of locomotion and is in use in all kinds of transportation, it is a development and part of the history of coal mining.

OTHER NATIONS ENGAGED IN COAL MINING

While the English and Scotch were at work developing the art of coal mining, much the same kind of development was going on in Germany, Belgium and France. These countries, however, were in the throes of war in the early part of the nineteenth century, and were subject to hostile invasion by the enemy armies so that during the period the Scotch and English were working out their problems of development, these countries subject to invasion, were halted in theirs. England secure in her tight little isle could go on in the ways of peace without the interruption of war for to the English mines the war was an added stimulus while to Germany, Belgium and France, it was desolation. This period which was so fertile in invention and discovery and development, was a period of peace in England and war on the continent, which no doubt, accounts for a large measure of the prestige of the English miners and manufacturers in the nineteenth century.

COAL DISCOVERED IN AMERICA

In America we find the first mention of coal was made by Father Hennepin in his journey through the Great Lakes in the latter part of the seventeenth century, but at that time this region was a vast wilderness which was inhabited only by savages and barbarians who could get all the fuel they needed for their wigwams and lodges from the forests. They made some pottery which was the only art which they possessed that would require fire. While they possessed some copper tools, there is no record of their having smelted copper from the ores. This region, therefore, had no need of coal at that time.

The first records we have of coal being discovered in the English speaking colonies of America was near Richmond, Virginia about 1700 but the mining of this coal was not begun until 1750 which was a half century later and then, the mining never developed into any considerable industry, for at that time there was still plenty of forest for fuel and the industries requiring coal had not been developed.

MINING IN PITTSBURGH DISTRICT OF PENNSYLVANIA

About 1786 shortly after the founding of Pittsburgh, the coal began to be worked along the banks of the Monongahela River, on the south side. This coal cropped out of the steep bluffs and was of easy access by tunnelling in the coal seam. The mines being near the tops of the hills, were easily drained and ventilated. The coal was dropped down the steep hills by means of incline planes. The loaded cars going down hauled up the empty ones. It was transported by wagon to the surrounding country and a great deal of it was put into the flat boats on the Monongahela River and floated on the "Freshets" when the river was high, down the Ohio and the Mississippi to the various towns along their banks, where it was usually bartered for molasses and sugar or exchanged for French and Spanish gold and silver coins at New Orleans.

This river trade was carried on by great flat boats and steam boat between the Monongahela River mines and points on the Ohio and Mississippi Rivers until very recently. The development of mines in West Virginia, Kentucky, Alabama, Tennessee have practically superseded this trade in the last few years.

Coal Mining was developed near Brownsville, Pa., about the same time as Pittsburgh but this coal was used largely for the production of glass. Both of these developments were in the Pittsburgh seam of bituminous coal.

DEVELOPMENT OF ANTHRACITE COAL

Anthracite coal was discovered in Eastern Pennsylvania in about 1766. It was first used for blacksmithing purposes in the immediate vicinity, and no considerable trade was developed for many years.

In 1791, some Philadelphia manufacturers investigated the possibilities of the anthracite coal along the Lehigh

River and in 1803, a company was formed to mine the coal. Several barge loads were taken to Philadelphia for use of the city engines but it was a failure as the coal could not be made to burn.

Later in 1812 the coal was successfully burned through learning by accident that it should not be stirred while burning like bituminous coal. After the accidental discovery the anthracite coal came into general use not only for manufacturing purposes but for domestic use. At the present time, its use as a domestic coal is in the highest place.

ADDITIONAL COAL DISCOVERIES AND DEVELOPMENTS

In 1838 the coal in the George's Creek region of Maryland was discovered and mined and successfully used in smelting iron. Later and quickly following, coal was discovered in various parts of the United States and put to use on all the various branches of industry that required it. The finding of coal of good quality and in abundance was always the beginning of industrial activity in the immediate vicinity of the coal.

In 1870 a vein of coal was discovered near Connellsville, Pa. which was found to make a valuable coke for smelting iron. Up to this time nearly all the iron mined in or west of the Allegheny Mountains was smelted with charcoal. The charcoal furnace was a small stack of stones built against the hillside where iron ore and limestone were found in abundance and also water power to drive the machinery to make the blast. The mountains were heavily timbered and the charcoal could be easily had so that those small furnaces of five or ten tons per day were quite an economical unit at the time.

About the same time that the coking coal was discovered near Connellsville, a very rich iron ore was discovered in the region about Lake Superior.

To bring these two necessary elements together meant transportation to a common point that was most advantageous. This point was Pittsburgh and the result was the rapid establishment of the vast iron furnaces and iron and steel mills of this region. Pittsburgh has become synonymous for iron and steel. The furnaces of the villages surrounding them in picturesque valleys of the Allegheny Mountains are a thing of the past. Many of the old furnaces are overgrown with huge trees. Mute witnesses of a vanished economic period.

The development of the modern coal mine has made the transformation. The coal industry of the United States has risen from the crude hillside drift with its horse and wagon transportation to the huge mines employing hundreds of workmen and thousands of tons daily output, necessitating railroad systems whose existence depends on the contributing coal mines. From no tonnage scarcely a century ago to the vast total of 450,000,000 tons in the past year of 1921.

The age of coal is here but we must bear in mind that we are in a period of rapid development in science and mechanic arts, and possibly sooner than any of us at this time can appreciate, we may turn to another source of power unknown to us now. By reviewing the inventions and discoveries of the last centuries, we can see the possibilities of such a change, but while our coal mining continues, it behooves all of us that are engaged in the art to use our best effort to make mankind better, the wiser and the happier while the Coal Age lasts.

Questions on Chapter I

Why was coal known as "Sea Coal?"
What was the cause for opposition to the early use of coal?
In the records of what countries do we find mention of the first coal?
How was coal first secured?
What were the first methods of transportation?
For what purpose was steam first used?
Who first discovered coal in America? What are our earliest records?

CHAPTER II

GASES, AND DEVELOPMENT OF SAFETY LAMPS

While the mines were developing below the water level and were requiring pumps and hoisting machinery to remove the water and coal, the miners encountered vitiated air that caused many accidents.

In the early days of mining all people were superstitious. So, it is not to be wondered at that the miner should think that the pits were inhabited by hobgoblins and other supernatural agencies to take away the miner's life.

The vitiated air caused the miners at times, to fall over in fainting spells from which they sometimes recovered. Sometimes they died. Sometimes the vitiated air exploded and burned the miners. Sometimes the explosion was so violent that it killed a number of miners.

These accidents were so frequent that it became necessary to stop them in some manner. The cause was little understood. It was a field for investigation. The chemist was called in to give his knowledge to the interests of the coal miners.

CLASSIFICATION OF MINE GASES BY CHEMISTS

These chemists who did the first exploring of the mine air, discovered that the "Blackdamp" of the miner's vocabulary was carbon dioxide or carbon monoxide, both gases being heavier than air. They were found by the miners on the floor of the mine. The "Firedamp" of the miner's vocabulary, they found to be methane, a gas lighter than air. This gas the miners found along the roof of the mine and particularly where the roof had fallen leaving a pocket. This pocket always contained "Firedamp" if any were present.

The miner discovered the "Blackdamp" by the flame of his light. It burned dim in the "Blackdamp" and gave him warning. The "Firedamp", however, usually went off with a violent explosion and without warning, killed those who ignited it.

METHODS OF CLEARING PLACES OF GAS OR "FIREDAMP"

The miners discovered that the "Firedamp" was ignited by their candles or lamps and one of the earliest methods employed to remove the danger was for the miner to get into a safe place, thrust his candle into the gas pocket in the roof and fire the gas intentionally. He was safe in that section of the mine until another accumulation had taken place. Another means adopted to remove the "Firedamp" was to drain it upward into the higher working. Owing to the lightness this could be done when the necessary boreholes or conduits were practicable. In few cases were they practicable so that this method was little used.

The diluting system of furnishing sufficient air to make the "Firedamp" non-explosive came into use in the early part of the nineteenth century and has been employed ever since.

DILUTING GAS WITH PURE AIR

This system requires sufficient atmospheric air to render the methane so dilute that it is less than an explosive mixture. It also, required ventilating apparatus that was capable of passing a large volume of air through the mine workings.

Mines in the early days were not laid out for the necessary ventilation. The airways were small and very tortuous. The pressure required to pass any considerable volume through such mines was too high for the ventilating apparatus of those times. Moreover, there were many nooks and crannies in those old mines which were not connected with the ventilating current.

Due to the imperfect ventilation and the imperfect layout of the mines for the ventilating air currents, there were many distressing accidents, for scores and sometimes hundreds of men and boys were killed.

These accidents not only killed the miners but usually wrecked the mines to such an extent that they were rendered idle until the tracks could be relaid and the timbers restored. The falls cleaned up and the circulation restored, all of which caused delay and expense and kept many men idle and the mine unproductive of coal.

NECESSITY FOR ENCLOSING FLAME OF LAMP APPARENT

It became necessary to find some way to work in the explosive mixture of the mine air. The chemist solved the problem. Science and the mechanical arts joined hands and produced the safety lamp in 1815.

It is a long story. This invention and it is the author's purpose to be as brief as possible.

The discovery and the invention were accomplished near New Castle, England.

DESCRIPTION OF FIRST METHOD FOR ENCLOSING FLAME OF LAMP

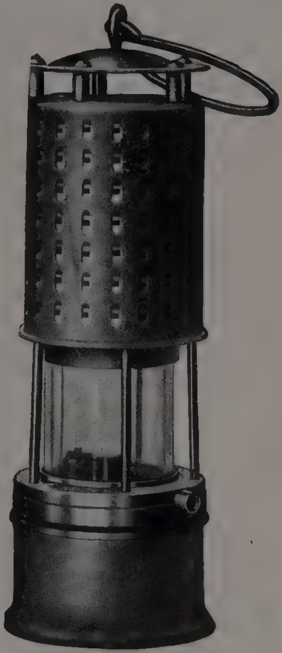
A Dr. Clanny who was witness of one of the distressing accidents in the vicinity of New Castle, was moved through a feeling for humanity to use his knowledge of chemistry to make a lamp that would burn in the explosive mixture of the mines. His idea was to insulate the flame of his lamp so it would burn and give off its light and not come in contact with the explosive mine air mixture. He attempted to accomplish this purpose by using a glass cylinder around his flame. The cylinder having a stratum of water above and below the flame. The air to feed the flame was pumped by a bellows through the lower stratum of water. The heated air escaped from the flame through the upper stratum of water.

This lamp solved the problem of burning a lamp in the mine air even if the explosive mixture were present but was too cumbersome to move about rapidly, and would go out if not handled with the greatest care. It was, therefore, not a practical lamp for mining. A different method of feeding the air to the flame was necessary.

To make this lamp a practical success, it must be moved about rapidly.

INVENTIONS BY DAVY AND STEPHENSON

Humphrey Davy, a chemist who was called into consultation regarding the Clanny lamp, recognized its possibilities. He proceeded to experiment with the lamp using the insulating idea, and at last produced a lamp having the flame surrounded with a wire gauze. The gauze was determined upon after much experimentation. It was found that a very fine wire would pass the air to the flame and keep the explosive mixture below the point of ignition. It was a safe lamp in an explosive mixture with certain exceptions which will be taken up later.



Safety Lamp

About this same time, October 1815, George Stephenson was at work on a safety lamp, which was along much the same lines as the Davy lamp. He also used the idea of Dr. Clanny to insulate the flame from the explosive mixture. The priority of the invention seems to have been settled in favor of Davy but both he and Stephenson got their basic idea from Clanny.

Working out the details on many inventions has been the means to fame and fortune. The basic idea is often discovered by one who has not the training nor facilities to complete, that is, develop the idea to a successful invention. This is particularly noticeable in this invention of the safety lamp. For a long time the use of the safety lamp successfully solved the mining problem in the fields where it was first established.

There were few explosions then for a number of years. The safety lamp was a safe lamp under conditions such as obtained in the mines of North England but it was not as easily handled as the common miner's lamp and did not meet the approval of the miners generally.

It was expensive and where used was the property of the mine owners.

DIFFICULTIES IN THE WAY OF INSTALLING SAFETY LAMPS

No mine would install the safety lamp until it was shown to be a very dangerous mine. It usually required a disastrous explosion to prove the mine was dangerous. So, the safety lamp was a long time coming into general use. A mine using safety lamps was considered a dangerous one by the miners and was avoided by them if work could be obtained in mines under less dangerous conditions. Those with open lights naturally being preferred.

Questions on Chapter II

In the progress of mining, what gases were encountered?

What was the effect of those gases on human life?

What were the common names of these gases?

What did the chemists discover that these gases were?

How were "blackdamp" and "firedamp" discovered by miners?

What means did the early miners take to clean the working places of gas?

CHAPTER III

ACTS OF PARLIAMENT OF ENGLAND AND STATES TO SAFEGUARD LIFE BY LAW

After a long series of disastrous explosions the English public demanded an investigation and means to prevent such distressing accidents.

The Parliament in 1835 appointed a committee "To inquire into the nature, cause and extent of those lamentable catastrophes which have occurred in the mines of Great Britain, with the view of ascertaining and suggesting means for preventing the recurrence of similar fatal accidents."

This committee took up its labors and found that under strong currents of air the air containing an explosive mixture would cause an explosion when passed through the wire gauze. Thus determining that the safety lamp was safe so long as it was worked in sluggish air currents and not moved about too fast by the miner. They also received many valuable suggestions as to more thorough ventilation of the mines and among these was a recommendation that the mines should be equipped with powerful fans to force a sufficient ventilating current of air through them. This recommendation was no doubt, the idea that later prevailed for the safe and efficient ventilation of the mine.

The committee however did nothing more than to report to Parliament.

No laws were enacted at that time but the investigation brought out facts and recommendations that later proved valuable.

LAW REQUIRING THE INSPECTION OF MINES

In 1843 a law making the inspection of mines a state function was passed by Parliament, and an inspector appointed. This appears to have been the earliest time in England and the United States where the state attempted to regulate the mining operations, although in continental Europe there seems to have been some supervision of the mines prior to this act.

From the time that the first mine inspector was appointed, great interest was taken in solving the ventilation problems in Great Britain. Societies were formed to study the problems and various schemes were devised and attempted to so ventilate the mines, that there might be no recurrence of the ghastly accidents that destroyed men's lives by the hundreds.

These societies and many individuals worked out and applied the necessary means to secure the mines against such disasters, at least as far as their knowledge at that time enabled them to go.

PARLIAMENT ENFORCES MINE INSPECTION

There were others who would not benefit by the knowledge at hand nor apply the existing methods of safety. The result was a continuous list of disasters that so shocked the public that Parliament was forced to pass an act in 1850 to place all coal mines under state inspection. Inspectors were appointed and their labors bore very beneficial fruit.

The accidents were reduced naturally. And, as their supervision was extended the loss of life and property due to explosions was lessened to such an extent that its beneficial character was acknowledged by all.

We, in the United States, were slower getting started in the mining of coal than Great Britain. In the early days of mining our mines were mostly drifts and not far underground. The ventilation was easy and the accidents were few. As our mines became more extensive and the distance underground greater, accidents became more frequent.

Desirable veins of coal frequently lay underneath the surface where they were not accessible by drift mining. The shaft mine became a necessity. The ventilation became more difficult year by year.

MINERS PETITION FOR STATE LEGISLATION

As many miners in the United States were aware of the dangers of many of these mines, in 1858 they petitioned the Pennsylvania Legislature for laws governing the mining of coal similar to those enacted in Great Britain.

Pennsylvania was at this time the most progressive mining state and was very rapidly developing its coal resources. Most of the Pennsylvania miners were originally from Great Britain and knew the benefit of State inspection. Their petition to the Legislature in 1858 received little attention and also, their subsequent petitions were unavailing until a great disaster occurred at Avondale near Plymouth, Pa., on September sixth, 1869. This disaster, however, was not an explosion of "Firedamp."

CAUSE AND RESULTS OF AVONDALE EXPLOSION

The ventilation was by furnace and shaft, with the furnace at the bottom of the shaft. At that time it was customary in Pennsylvania to have but one shaft for each coal mine. Partitions were made in the shaft for hoisting and ventilating. In the Avondale shaft the ventilating furnace was at the bottom of the shaft. The furnace man that morning used a heavy charge of wood to light his fire, immediately setting fire to the partition in the shaft. As the miners had gone to work in the mine and the flames of the burning partition set fire to the breaker directly over the shaft, the miners had no way of escape. They all perished. This disaster was directly responsible for an act of the Legislature, passed in 1870 for the purpose of creating a state board of inspectors to look to the safety and health of the miners as well as the property of the owners.

LEGISLATION IN PENNSYLVANIA AND OHIO

In the state of Ohio about the same time legislation was enacted making the inspection of mines a state function.

From this time until the present, through and in consequence of a series of disasters, the state has gradually extended its function of supervision of mines until it has eliminated many of the causes and has required means for the prevention of these accidents.

Pennsylvania and Ohio being the older of the mining states, have taken the lead in such supervision and they have gradually built up a staff of mine inspectors which is the model of what public servants should be in honor, courage and devotion to duty. The author is personally acquainted with many of these state inspectors throughout the mining states and speaks from personal knowledge.

While the two states above mentioned have been using their efforts to make mining safe and sanitary, other states have done likewise. Most of them have patterned their ventilation legislation from the laws of Pennsylvania. The latest act of the State Legislature bearing on ventilation is quoted below:

PENNSYLVANIA MINING LAW FOR VENTILATION

"The operator, or the superintendent, shall provide and maintain ample means of ventilation to furnish a constant and adequate supply of pure air for the employes. In a non-gaseous mine, the minimum quantity of air shall not be less than 150 cubic feet per minute for each person employed. In a mine wherein explosive gas is being generated in such quantities that it can be detected by an approved safety lamp, the minimum quantity of air shall not be less than 200 cubic feet of air per minute for each person employed therein, and as much more in either case as one or more of the inspectors may deem requisite. The return air from each split, where 70 to 90 persons are employed, shall be conducted by an overcast, or an undercast, into the return airway, which shall lead to the main outlet.

"The ventilation shall be conducted through the main entries, cross entries, and to the working faces of all working places of the mine, in sufficient quantities to dilute, carry off, and render harmless, the smoke and the noxious and dangerous gases generated therein to such an extent that all working places and traveling roads shall be in a safe and healthful condition for the persons working and traveling therein.

"No permanent door shall be erected or allowed to remain in the main entry of any mine, unless its removal shall be deemed impracticable by the inspector.

"**Section 2**—Where five or more persons are employed at any one time in a mine, it shall be the duty of the operator, or the superintendent, to provide ample ventilation in accordance with section 1 of this article; provided that, it shall not be lawful to use a furnace for ventilating any mine wherein explosive gas is being generated.

"Six months after the passage of this act, not more than 70 persons shall be permitted to work in the same continuous air current, unless, in the judgment of the inspector of the district, it is impracticable to comply with this requirement, in which case, a larger number, not exceeding 90 persons, may be permitted to work therein.

"**Section 3**—The mine foreman shall see that proper cut-throughs are made in all the room pillars, at such distances apart as, in the judgment of the inspector, may be deemed requisite, not more than 35, nor less than 16 yards each for the purpose of ventilation.

"**Section 4**—The quantity of air passing a given point shall, be ascertained by an anemometer, the measurements to be taken by the mine foreman once every week, at, or near, the main inlet or outlet airway in the mine, and, also, at the last cut-through in the last room and in the entry beyond the last room turned. Said measurements shall be taken on days when the men are at work.

"**Section 5**—In all mines, all new stoppings in cut-throughs between the main intake and return airways shall be substantially built of masonry, concrete, or other incombustible material, and shall be of ample strength; and in mines generating explosive gas all new stoppings and renewal of old stoppings in cross entries shall be built of masonry, concrete, or other incombustible material. Stoppings in cross entries in non-gaseous mines, may be built of timber. All stoppings shall be kept in good condition so as to keep the air up to the working faces. Temporary stoppings shall be erected in cut-throughs in rooms to conduct the ventilation to the face of each room and such stopping may be constructed of timber of brattice cloth.

"**Section 6**—Every ventilating fan at non-gaseous mines shall be kept in operation continuously, day and night, unless operations are definitely suspended, except when written permission is given by the inspector to stop it. The said permission or a copy thereof, shall be posted by the mine foreman in a conspicuous place at the entrance, or entrances to the mine, and shall state the particular hours that the fan may be stopped. The inspector shall have the power to withdraw, or modify, such permission at any time and in any manner he may deem best. In all cases, however, the fan shall be started two hours before the time to begin work. Every ventilating fan at gaseous mines shall be kept in operation continuously, day and night, unless operations are definitely suspended: Provided that, should it at any time become necessary to stop the fan at any mine (gaseous or non-gaseous) on account of accident to part of the machinery connected therewith, or by reason of any unavoidable cause, it shall be the duty of the mine foreman, or the assistant mine foreman, in charge, after first having provided for the safety of the persons employed in the mine, to order said fan stopped for necessary repairs.

"Every ventilating fan shall be provided with a recording instrument by which the number of revolutions, or the effective ventilating pressure, of the fan shall be registered and the registraton for each day with the date thereof, shall be kept in the office of the mine, for future reference, for one year.

"No main or principal fan shall be placed inside of any mine. No auxiliary fan, unless driven by electricity or compressed air, shall be placed in any mine. If the fan be electrically driven, the motor shall be placed in the intake airway.

"Every ventilating furnace in a mine shall be properly attended to and operated by a competent person employed by the mine foreman for that purpose for two hours before the appointed time to begin work, and constantly thereafter during working hours.

"**Section 7**—In every mine all new air bridges, overcasts, or undercasts, shall be substantially built of masonry, concrete or other incombustible material of ample strength, or shall be driven through the solid strata. It shall be the duty of the mine foreman to see that these bridges are properly built and are of ample strength.

"**Section 8**—In every mine the doors used for guiding and directing the ventilation shall be so hung and adjusted that they will close of themselves, or shall be supplied with springs or pulleys so that they cannot remain open. All principal doors shall be placed, that when one door is open, another which has the same effect upon the same current, shall be closed and remain closed to prevent any stoppage of air current. An attendant shall be employed at each principal door (that is the door that controls the main air current in the entries) through which cars are hauled for the purpose of opening and closing it for the employes and cars to pass in and out from the workings, unless a self-acting door, approved by the inspector, is used. A hole for shelter shall be provided at each door to protect the attendant from danger from the cars while performing his duties. Persons employed for this purpose shall remain at the doors at all times during working hours: Provided that, the same attendant may attend two doors, if his absence from the first door does not endanger the safety of the employes. At every door, on the incline plane, or road whereon haulage is done by machinery, an attendant shall always be on duty during working hours and at every door on said plane, or road, an extra door shall be provided for use in case of necessity. Wherever a principal door is placed, an extra door shall also be provided to be used in case of necessity.

"**Section 9**—No product of petroleum or alcohol or any compound, that in the opinion of the inspector, will contaminate the air to such an extent as to be injurious to the health of the miner, shall be used as motive power in any mine.

"**Section 10**—If any person shall construct, or cause to be constructed or used, or permit to be used, from or after the date of the passage of this act, any sewer, or other method of drainage, from any building, or dwelling house, for the carrying of sewage, offal, refuse, or other offensive matter into any operating mine, or an entry way or passage, or room in any mine, (such entry way, passage or room being used for ventilating or drainage purposes or for a traveling way), such persons shall be guilty of a misdemeanor, and, upon conviction thereof, shall be sentenced to a fine not exceeding $1000 and undergo an imprisonment not exceeding one year, either or both at the discretion of the court."

This legislation or similar legislation is being forced in all the states for the protection of the miners. It is the result of long years of effort to obtain such legislation and represents the wisdom embodied in law, and has been learned through the suffering caused by the numerous mine disasters that have shocked humanity.

Questions on Chapter III

Why did the English Parliament act to investigate mining?
What were the recommendations of the committee?
When was the first law passed, governing mine inspection?
What was the effect of enforcing mining laws in England?
What disaster hastened mining legislation in Pennsylvania?
What states were first to appoint mine inspectors?
Who must provide the ventilating equipment?
How shall the ventilation be conducted through the mine?

CHAPTER IV

GASES COMMON TO MINES

That science which deals with the changes in the composition of substances is known as Chemistry.

Those who deal with the mining art must have a knowledge of the science of chemistry to intelligently pursue the art.

Particularly is this true of the ventilation problems that present themselves to every mine.

The various substances that are encountered daily as the mines develop are undergoing chemical changes. The more rapid the development of the mine, the more rapid these changes take place. The pushing forward of the entries and other working places in the coal mine liberates numerous gases that have been confined in the coal strata since the formation of the coal. Principally among these gases are marsh gas, the "Firedamp" of the miners, carbon monoxide, the "Whitedamp" of the miners, carbon dioxide, the "Blackdamp" of the miners and hydrogen sulphite. The latter gas being unknown to the miner in his vernacular.

The author assumes that the reader has an elementary knowledge of chemistry, so that it will not be necessary to define the common chemical terms or reactions.

If there is any doubt of any of the terms or reactions expressed the reader can readily consult his chemistry and verify the statements that he finds here.

MARSH GAS, CH_4 OR METHANE

Marsh gas is a chemical compound of carbon and hydrogen and is known to the chemist by the symbol CH_4.

One atom of carbon and four atoms of hydrogen, chemically combined. This gas is evolved from most coal seams during the process of mining. In some workings it exudes from the coal seam with such force as to cause splinters of coal to fly from the faces. Sometimes it issues from crevices with a hissing sound and sometimes it bubbles up from the floor of the mine through the water. It is transparent, colorless, and inodorous. It is slightly soluble in water. It burns, forming carbon dioxide and water. When mixed with air in certain proportions, the mixture explodes if a flame or spark comes in contact with it. Being lighter than air, it diffuses readily with the atmosphere in the mine and makes the deadly explosive mixture that has caused so many disastrous explosions. It is injurious to health when breathed in large quantities but is not poisonous. It is evolved from the chemical transformation of the carbonaceous matter of which coal is formed, when the decomposition takes place in the presence of water and the exclusion of air.

CARBON MONOXIDE, CO OR "WHITEDAMP"

Carbon monoxide, "Whitedamp" is a chemical compound of carbon and oxygen and is known to the chemist by the symbol CO, one atom of carbon and one atom of oxygen, chemically combined. This gas is the product of combustion when there is insufficient air to make the combustion complete. It can be detected in open grate coal fires by the blue flame at the top of the fire. The interior of the coal usually gets insufficient air to effect complete combustion and the carbon monoxide is generated in the interior of the fire and rises to the top and burns with a blue flame. In the mines it is often the product of gob fires and powder blasts when the powder is not completely burned by the explosion. It is present after the explosion of marsh gas when insufficient air has been present to make the explosion complete. It is colorless, tasteless, and inodorous, and is insoluble in water and when it burns it forms carbon dioxide. It is exceedingly poisonous when inhaled. It produces stupor and acute pains in the head, back and limbs, and sometimes causes delirium and death.

CARBON DIOXIDE, CO_2 OR "BLACKDAMP"

Carbon dioxide is a chemical compound of carbon and oxygen and is known to the chemist as CO_2, one atom of carbon and two atoms of oxygen in a chemical combination. This gas is a product of the complete combustion of carbon and oxygen where there is sufficient air to effect a change. It is the principal compound of carbon and oxygen and is commonly known as carbonic acid gas. It is present in the atmosphere at all times, in relatively small quantities. The air that we exhale from our lungs is largely carbon dioxide. This gas is colorless, at ordinary temperatures and at a high pressure it is converted into a liquid. It has slightly acid taste and smell. It is not combustible nor does it support combustion. It already holds in combination all the oxygen that it has power to combine with. It is heavier than air and lies close to the floor of the mine, which renders it difficult to remove with the ventilating current. It is not a poisonous gas but when breathed into the lungs it excludes oxygen causing headache and pains and nausea and if not expelled by breathing fresh air, will cause death by suffocation.

It is found in most coal mines being the result of firing shots, breathing of animals, slow decomposition of various substances in the mine which contain carbon and is one of the resultant gases from an explosion of marsh gas.

SULPHURETED HYDROGEN, HYDROGEN SULPHIDE, H_2S

Hydrogen Sulphide is a chemical compound of hydrogen and sulphur. It is known to the chemist by the symbol H_2S, two atoms of hydrogen and one of sulphur in chemical combination. This gas is generated by passing hydrogen gas over highly heated sulphur. The two elements combine and form the compound. It is a colorless gas but has the odor of rotten eggs and can readily be detected in the mine by its smell. When mixed with the proper proportion of air it is highly explosive. It is a very dangerous gas for it explodes in the proper mixture with air at a low temperature. It is also poisonous when inhaled in large quantities.

It is usually found in old workings being the product of disintegration of pyrites found in the coal. These are the sulphur balls of the mines and are known to the chemist by the symbol FeS_2.

NAMES AND SYMBOLS FOR THE COMMON GASES

There are a number of other gases generated from the strata of coal and rock which appear during the mining operations. They are of minor importance. The common and very dangerous ones enumerated are:

Methane (Marsh Gas)	CH_4
Carbon Monoxide	CO
Carbon Dioxide	CO_2
Hydrogen Sulphide	H_2S

It will be observed at a glance that all of these but the last are the combination of carbon with another gas. The last being a gas combined with sulphur.

DEFINING THE TERMS MIXTURE AND EXPLOSIVE MIXTURE

The other gases generated but not enumerated are of minor importance in the ventilation problem because the ventilation necessary to dilute and remove and render harmless the more important gases takes care of these gases at the same time for they are a part of the same mixture. The terms mixture and explosive mixture have been used frequently. What is meant by these terms? When two substances combine chemically, they evolve heat. If no heat is evolved there is no chemical combination and the mingling of the two substances is then a mixture. Air for example is a mixture of oxygen and nitrogen. About twenty-one per cent oxygen and about seventy-nine per cent nitrogen. They are not in chemical combination in the air. They are simply a mixture. Oxygen is the most prevalent and widely distributed element. It forms between forty and fifty per cent of the earth's solid crust, eighty-eight per cent of the water and twenty per cent of the air. It is the most active substance known.

Nitrogen on the other hand is a very inert gas. It does not burn nor does it support combustion. It is the neutral substance in the air that prevents the oxygen from rapidly combining with everything else.

The oxygen in the air is free oxygen.

The nitrogen in the air is free nitrogen.

An explosive mixture is a mixture of air and some gas or gases which mingled in given proportions may be exploded by a flame or spark, in which case the heat from flame or spark causes chemical action between the gas or gases and the oxygen of the air. This chemical action is so rapid that the heat and expansion due to the sudden change cause the explosion. By confining the explosion as is done in a mine, great violence occurs, which destroys life and property in proportion to the force and extent of the explosion. The most familiar example of this action is in the explosive mixture of air with marsh gas. About seven per cent marsh gas and about ninety-three per cent air make an explosive mixture. This is regarded as the lowest percentage that will cause an explosive mixture with air. About seventeen per cent marsh gas and eighty-three per cent air is regarded as the highest percentage of marsh gas that will cause an explosive mixture with air. A mixture then that is between seven per cent marsh gas and seventeen per cent marsh gas with corresponding percentage of air is the most dangerous mixture. The most violent in its explosive force. The mixture of this gas with air when the percentage is below seven per cent is not an explosive mixture, neither is it when the percentage is above seventeen per cent. There are other gases in the mine air which when mingled in the mixture change these limits. Also the temperature and barometric changes alter the limit somewhat, but not to a very great extent.

It will be observed that the mingling of oxygen and nitrogen in the mixture known as air does not generate heat. This mixture is therefore, not chemical action. In the mixture of marsh gas and air, known as an explosive mixture, heat is not generated until the presence of a flame or spark causes the mixture to take on its chemical action. The effect of the chemical action is heat and sudden and violent expansion of the gases. The early miners knew nothing of the science of chemistry. Their want of this knowledge caused many explosions with the resultant loss of life and distress of the survivors together with immense property losses.

The present day miner with his knowledge of this science is enabled to detect and foresee to a very large extent the dangers in the mines.

Through this knowledge he is able to provide the means to avert the disasters that were so common years ago. He knows of the chemical substances in the mine. He knows the reactions due to the mingling of these chemical substances. He can provide the necessary apparatus to care for these reactions before they assume proportions that cause loss of life and property.

The safety lamp with intelligent use and care, minimizes the danger of marsh gas in advance workings of old workings that are abandoned. Adequate ventilation properly conducted through the mine renders the other gases harmless.

There is one other substance that has not been touched upon, that is also a very dangerous element of explosions. It is the coal dust in suspension in the mine air and along the floors, and lodged in the nooks, crevices and crannies of the mine. This matter will be treated later.

Questions on Chapter IV

Describe CH_4 or marsh gas.
Where is it found in mine workings and why?

How is marsh gas formed?

What do we understand by CO, carbon monoxide or "white damp"? Describe fully.

How is CO formed?

What is the effect of CO on life?

What chemical change produces CO_2?

Where is CO_2 found and why?

How is hydrogen sulphide generated? Under what conditions is H_2S explosive? What is the effect of H_2S on life?

What is meant by the terms mixture and explosive mixture?

Which is the most prevalent and widely distributed element?

Of what elements is air, ON_4, composed?

CHAPTER V

FORCE, PRESSURE AND POWER

That science which deals with motion, light, sound, electricity and magnetism is known as "Physics."

Those who deal with the mining art must have a knowledge of the science of physics to intelligently pursue the art.

Particularly is this true at the present time, when almost everything about the mine is moved or operated or controlled by some force other than animal power.

Assuming then, that the reader has some elementary knowledge of physics, it will not be necessary to define the fundamental laws that govern matter.

In the ventilation of the mine we must cause a flow of air through the working, not only that the men working therein may have fresh air to breathe, but there must be sufficient air flowing through the mine to dilute the gases, so that they will be rendered harmless to breathe. Also, that they may in the case of explosive gases be so diluted that there can be no explosive mixture possible.

In many mines there is very little marsh gas generated, yet there may be large quantities of Carbon Dioxide, "Blackdamp."

For these mines sufficient air must be passed to sweep out of the mine the noxious gas.

The ventilating current which is sufficient to remove the carbon dioxide or dilute the marsh gas will be sufficient to take care of all the other gases encountered.

Coal dust suspended in the air or lying on the floor of the mine and in the nooks, crevices and crannies, is a substance that must be dealt with separately.

Air, the atmosphere is a mixture we are so familiar with that we do not appreciate readily that it has mass and requires force to move it. We think of it as the wind and it blows and moves without apparent cause, and seemingly without any propelling force. When we cause it to circulate through a mine, we learn that it requires force and sometimes a very large force to propel it.

When any change occurs or tends to occur in the momentum of a body, we ascribe it to a cause called force.

VENTILATING PRESSURE

It is obvious that if we cause the mass of air within a mine to move and maintain its momentum, we must apply force to move it and keep it in motion. This force which causes and maintains motion of the air through the mine, we term work or energy. As the force is constantly applied while the air is in motion, we call it pressure and as the pressure is applied to the air to circulate through the mine and ventilate it, we term this pressure "ventilating pressure." This ventilating pressure is exerted on the entire mine but it is obvious that it is at the maximum where the pressure is originated and tapers off to zero or atmospheric pressure at the other opening or openings.

HOW TO FIND THE PRESSURE

The ventilating pressure is usually measured as near the origin of the pressure as is practicable. In a drift mine it is measured within one or two hundred feet of the drift mouth where the pressure originates and the air is all in one column. In a shaft mine it is measured in the shaft and the velocity reading as near the bottom of the shaft as possible and as near the origin of pressure as it can be obtained. The point at which the pressure is taken and the point at which the velocity is read should be as near together as is attainable. It is obvious that the pressure is the same on any given section of the mine, so that at the point of reading the total pressure P will be the product of unit pressure or pressure per square foot p multiplied by the area in square feet a so that our formula for the total pressure becomes $P=pa$ but this pressure pa exerted on the mine air moves it at some given velocity v which gives us the factor pav when the element of time is taken into consideration. But, the area multiplied by the velocity av is the volume V of air passing the given point in a minute if a minute is the unit of time so that our unit of force or work or energy u exerted on the moving column of air in the mine becomes plain in the formula $U=VP$.

HORSE POWER PRACTICALLY DEFINED

We usually think of this force in terms of horse power. A horse power being the force required to move a weight of 33,000 pounds one foot in one minute. It will be noted here that this is an empirical unit without much reference to the power of a horse, such as is used about the mines but it is a good unit of computation and has stood the test of time. It was first used by Watt, the inventor of the reciprocating crank steam engine. He determined that a large brewery horse could hoist beer barrels from cellars of London breweries at the rate of 33,000 pounds one foot in one minute and he adopted this unit as the standard unit for the work his engines could perform. The formula for this form of force is:

$$H\,P = \frac{P\,L\,A\,N}{33{,}000}$$

In which P is the steam pressure in pounds exerted on the piston of the engine. L the length of the stroke of the engine in feet. A the area of the piston in square inches and N the number of strokes of the engine in one minute. The divisor, 33,000 being Watt's unit of horse power force. It will be noted here that the only unknown quantity in this formula for any given engine is the P which is in practice the mean effective pressure of the piston on the engine throughout its entire stroke. The factor is obtained by an instrument known as a steam engine indicator. This instrument was also invented by Watt.

THE MOTIVE COLUMN

The air within the mine has a definite mass. This mass must be moved at some given velocity to supply the requirements of the miner. It must be moved in a given time. This mass of air moving through the mine is known as the motive column. The force required to propel this motive column not only must overcome the inertia of the mass of air, but must overcome the resistance offered to its passage by the sides, roof and floor of the mine. The speed at which the mass moves is another factor determining the force required.

The force required to pass the motive column is therefore made up of three factors, mass, speed and resistance.

How are these factors determined in the every day practice of the mine? The mass of air is determined by the number of cubic feet of air passing a given point in a unit of time, usually one minute, and is termed the volume.

Questions on Chapter V

What is the cause of a change in the momentum of a body?

What is meant by ventilating pressure?

Where is ventilating pressure measured?

How do we find the total pressure?

What is meant by the term horse power?

Define the motive column.

What three factors comprise the force required to create the motive column?

What is meant by the mass of air?

CHAPTER VI

LAWS GOVERNING THE FLOW OF AIR IN MINES

The speed of the air is determined by an instrument known as an anemometer.

The resistance is determined by an instrument known as a water gage. The force required therefore to pass the motive column is in terms of horse power represented by the formula

$$H\,P = \frac{VP}{33{,}000}$$

The total pressure P is the resultant of two factors, one the reading in inches on the water gage and the other the constant 5.2 which represents the pressure per square foot, of one inch height of the water column in the water gage. This constant 5.2 is in use in practice in all coal mining fields regardless of the altitudes but it is correct only at sea level. The formula then for the work on the motive column of air is in terms of horse power as applied in every day practice.

$$H\,P = \frac{a \times v \times wg \times 5.2}{33{,}000}$$

In this discussion there are many factors that may not be clear to the reader. To make it clear let us discuss an example of every day practice. The author has in mind one that is quite clear and comprehensible.

A mine in a low seam of coal is passing 116,000 cubic

Water Gage

feet of air per minute. The area of the airway immediately in front of the origin of pressure is 48.146 square feet. The mean velocity as read by the anemometer is 2450 feet. The water gage as read at the origin of pressure is 5.4 inches. What amount of force is in this moving column of air as expressed in terms of horse power? Let us take our formula and insert the above data then:

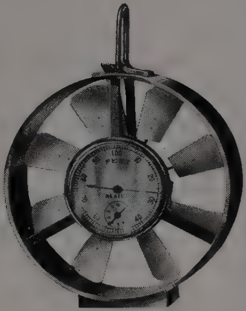
$$H\,P = \frac{48.146 \times 2450 \times 5.4 \times 5.2}{33{,}000}$$

$$= 98.4 \text{ horse power on the air}$$

It must be borne in mind that this power or energy or force, as we choose to call it, is the energy in the air and could the moving column of air be utilized to drive some other form of work, it would exert a like power. It must be carefully noted that this power in the air bears only relatively on the power used in the originator of the pressure. When the originator of the pressure is taken into consideration then the question of efficiency in its many phases comes into play and this will be treated later.

The example given above is one in actual practice and is going on daily where the velocity, area and water gage are accurately known by observation.

But in the projection of a new mine when no workings are in existence, but only plotted on a map. How, then can we determine the power or force to move the column of air?



Anemometer

THE COEFFICIENT OF FRICTION, HOW OBTAINED

When the ventilation of mines became a study during the nineteenth century, a number of mining engineers took observations of the mines in which they were in close contact, where they could get accurate observation of the friction of the air against the sides, roof and floors of the mines, and after taking many of these observations from their own experience and from the mines under observation, they deduced a coefficient of friction which when applied to the rubbing surface of the mine enabled the engineer to figure out the probable water gage. Each of these engineers worked out his own coefficient from the data observed in the field of his observations and, of course, they varied from each other. Those commonly used among mining engineers in this country are Atkinsons, Fairleys, and Murgues. They are as follows:

Atkinsons...............	.0000000217
Fairleys.................	.00000001
Murgues................	.000000009

These coefficients are the result of experience and are practical. They can be used only by those who have a wide experience and knowledge of mining conditions.

It will be observed that Atkinson's k is nearly two and a half times Murgue's k and unless the engineer has a wide experience, he does not know which coefficient to use on the particular mine that is the subject of the calculation.

The author has had some mines come under his observation wherein the coefficient $k = .000000069$ and others where the coefficient $k = .000000006$. This last figure being less than ten per cent of the former. The coefficient $k = .000000006$ will apply to air shafts that are well lined.

USE OF THE KSV² FORMULA EXPLAINED

The use of this ksv^2 formula will often lead to observations that will be beneficial in correcting bad conditions in the mine or in short airways, or in air shafts. If the air current be short circuited so as to pass only through the air shaft or other airway under observation. Then the actual water gage can be observed and compared with the ksv^2 formula. If the coefficient is low, the airway is proven in good condition and if it is high, the airway is in bad condition. It will be observed here that the water gage, the "U" tube, is the most accurate instrument used in the measurement of the air and its findings always indicate the condition of the airways.

That the use of this formula may be made clear, let us take an example to illustrate it:

A mine is passing all its air through an airway 48 square feet cross sectional area, 6 feet high and 8 feet wide. The velocity is 1320 feet per minute. The distance is 10,000 feet. Inserting specific values using Atkinson's coefficient in the formula:

$$W\,G = \frac{ksv^2}{a \times 5.2} \qquad \text{we have}$$

$$W\,G = \frac{.0000000217 \times 28{,}000 \times (1320^2)}{48 \times 5.2}$$

$$= 4.24 \text{ inches}$$

Now using Murgues coefficient in the same formula we have:

$$W\,G = \frac{.000000009 \times 28{,}000 \times (1320^2)}{48 \times 5.2}$$

$$= 1.76 \text{ inches}$$

The reader will observe that it makes quite a difference which of these coefficients is used. The engineers in charge of these calculations must have the necessary experience to apply the proper coefficient to suit the particular mine in question. The use of this ksv^2 formula is therefore a matter of experience and judgement.

FINDING THE VELOCITY BY USING THE PITOT TUBE

Sometimes the location of the fan with respect to the drift or the air shaft makes the use of the anemometer difficult or impossible. In which case, a Pitot tube can be used to register the velocity. The Pitot tube is an instrument which consists of two water gages so connected that the tubes leading from the water gages to the airway in which the air velocity is desired, read both the static pressure and the total pressure. The difference between the pressures is the basis for calculation of the velocity of the air in the drift or air shaft. This instrument is illustrated below and the formula for converting the reading on the Pitot tube from pressure to velocity as used by the United States Navy is also given:

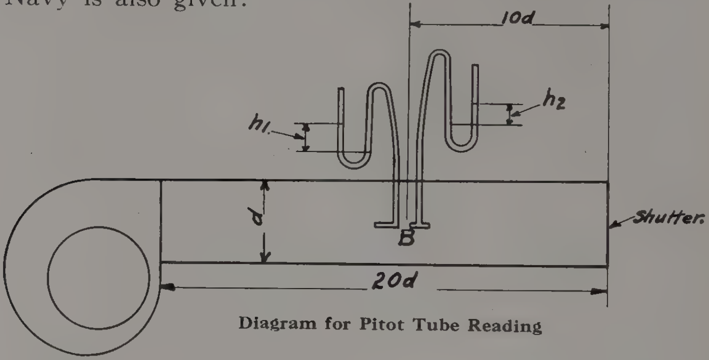


Diagram for Pitot Tube Reading

Formulas Used in Calculating Results

(1) $v=997\sqrt{\frac{h_3}{W}}$

(2) $V=Av$

(3) $H.\ P.\ \text{of Air}=\frac{5.2\ h_1\ Av}{33{,}000}=\frac{h_1\ Av}{6345}$

V = Volume in cubic feet per minute.
v = Mean velocity in feet per minute.
h_1 = Total Head in inches of Water at center of Duct.
h_2 = Static " " " " " " " " "
h_3 = Velocity" " " " " " " " "
$h_3=h_1-h_2$
A = Area of duct in sq. feet at B.
W = Weight of air in lbs. per cubic foot.

These formulas assume that a center velocity of 2200 feet per minute corresponds to an average velocity of 2000 feet per minute. This corresponds to the formula $v=\sqrt{1.95gh}$ where h is the average velocity head and for the Horse Power formula $H.P.=\frac{h_1 \text{ x } \sqrt{h_3}\ A}{1.575}$ where h_1 is the average total head, and h_3 is the average velocity head.

It will be observed that one of the water gages registers the static pressure. This is the one usually termed water gage in use in mine measurements. The air current passes the end of the tube that leads to the water gage and at right angles to it. The other water gage registers the total pressure. This gage is not used ordinarily in mine measurements. The tube leading to this water gage has its end bent parallel to the current so that the air current enters the end of the tube directly in its line of motion. This gage always reads higher than the static water gage and is the sum of the static and velocity pressure. The reading with this instrument is more accurate than an anemometer for it takes into consideration factors that are negligible on the anemometer as the temperature and weight of the moving column of air.

PRACTICAL APPLICATION OF PITOT TUBE

To make the use of this instrument clear let us take an example and applying the formula find the velocity of the air in a shaft 80 square feet cross sectional area where the total head is 3.75 inches and the static head is 3.25 inches, temperature 60 degrees, our formula for velocity is

$$V = 997\sqrt{\frac{h^3}{w}}$$

Inserting specific values we have

$$V = 997\sqrt{\frac{.5}{.076*}}$$

$$= 2552 \text{ feet}$$

(*The weight of a cubic foot of air at 60 degrees temperature Fahrenheit.)

Now having the velocity, what is the volume of air flowing through the shaft? Using the formula:

$$V = A\,V \qquad \text{we have}$$
$$= 80 \times 2552$$
$$= 204{,}160$$

This is true for the center velocity but as 2200 feet of center velocity corresponds to an average velocity of 2,000 feet, the average velocity in this case would be 2,320 feet which would make the actual volume flowing through the shaft 185,600 cubic feet.

We now have the velocity and the volume. What will be the force or work propelling this volume at the stated pressure? Using formula

$$H\,P = \frac{5.2\,h. \times Av}{33{,}000} \quad \text{we have}$$

$$H\,P = \frac{5.2 \times 3.75 \times 80 \times 2{,}320}{33{,}000}$$

$$= 106.66$$

POWER REQUIRED TO PROPEL AIR VARIES AS THE CUBE OF VELOCITY

The ordinary method of anemometer and static water gage reading would show this force to be but 95.03 Horse Power. The reader will observe that the volume of air is directly proportional to the area of the airway through which it passes and also the velocity of the air. The force or power required to propel the air varies as the cube of the velocity of the air.

In applying any of these power formula it will be observed that the factor of greatest importance is the velocity of air. Below is given a table of air velocities with the corresponding water gage pressures. This table is given in inches of water gage pressures. It will be found useful in calculations:

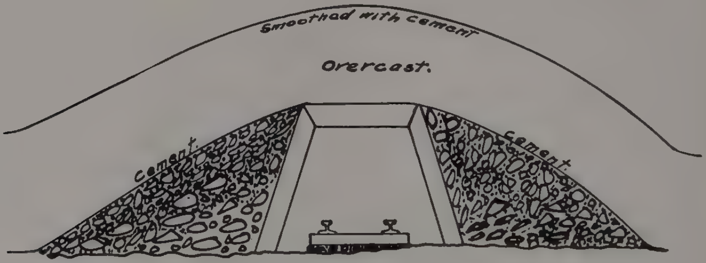
Pressure per Sq. Ft. in Inches of Water Gage	Velocity Due to the Pressure in Feet per Minute	Pressure per Sq. Ft. in Inches of Water Gage	Velocity Due to the Pressure in Feet per Minute
⅛	1393	2	5587
¼	1971	2½	6259
⅜	2414	3	6846
½	2788	3½	7363
¾	3414	4	7905
1	3946	4½	8385
1¼	4362	5	8838
1½	4836	6	9672

WATER GAGE VARIES AS SQUARE OF VELOCITY

A careful examination of this table will show how rapidly the water gage rises with the speed of the air. For example, note that 1 inch of water gage corresponds to 3,946 feet of velocity and 4 inches of water gage corresponds to 7,905 feet of velocity. If an airway of 50 square feet cross sectional area requires 4 inches of water gage to pass a given quantity of air, then an airway of 100 square feet or two airways of 50 square feet will require but 1 inch of water gage to pass the same quantity. The water gage varying as the square of the velocity. Likewise, if 100 horse power is required to pass a given quantity of air through a 50 foot airway, the power required to pass the same quantity through a 100 foot airway or two 50 foot airways will be approximately one-fourth of 100 horse power or twenty-five horse power.

LARGE AND UNIFORM AIRWAYS FOR CORRECT VENTILATION

From the above discussion of the laws governing the flow of air in mines, it will be observed that the greatest physical difficulty comes from small and tortuous airways. These small airways cause great resistance and this resistance must be overcome with a corresponding application of force. The long and tortuous airways cause resistance and in direct proportion to their length, but the small airways cause resistance as the square of the velocity of the air flowing through them. The air flows with the least resistance in the airways of uniform section. Those airways that have great falls of roof in them, even when cleaned out thoroughly, impede the flow of air for the velocity slackens in these enlarged places and requires an added impulse to resume its normal speed where the airway again assumes its natural size.



Overcast

It is a very common mistake on the part of mining men to regard these enlarged places in airways as beneficial to ventilation. On the contrary they are very injurious, not only owing to the slackening of speed of the air but because of the vibrating of the air rotating on itself along the roof and walls of such enlarged places. It should be borne in mind that anything that causes the air current to be diverted from its path of motion which is a straight line, will require force to change the direction of the air current. Observation will convince anyone that in these enlarged places large quantities of air are diverted from the main column and are eddying and swirling about along the sides and roof of the airway. This diverted air is not moving forward, hence, all the power required to keep it in constant agitation is wasted. Frequently where overcasts are in use, a hole is shot in the roof of the mine and the haulage way covered over without sufficient care being taken to have the overcast so made that its area will be as large as the airway leading to and from it. The approaches to the overcast should be made a gentle slope as well as in the overcast above the haulage way and the whole construction made as smooth as possible. These points in the ordinary mine are very much neglected. They require the greatest care.

COAL DUST AN EVER PRESENT DANGER

One of the greatest physical difficulties of ventilating the large modern mines is coal dust. We have referred to explosions of gases, and the use of the safety lamp to overcome the danger attending mining when "Firedamp" was prevalent. A great many explosions occurred when the greatest care was exercised to remove or dilute the "Firedamp." It was found by making many tests and experiments, that some of these mysterious explosions were traceable to coal dust.

In a dry mine where a generous supply of ventilation is furnished, the coal dust remains in suspension in the air. It is packed against the floors, roof and walls of the mine in all possible nooks and crevices. These supplies of dust are ever prevalent and ready in case of an explosion. Will this dust explode? And, if so, under what conditions? Under the first experiments it was determined that a small pocket of marsh gas might be exploded among coal dust and the coal dust would add to the explosive force of the marsh gas. Afterwards, through further experiments, it was determined that coal dust, itself, could be exploded without the presence of marsh gas. The explosion could be effected by a heavy charge of powder or dynamite in what is known as a "Blownout Shot." The heat in this shot being so intense as to explode the coal dust. The theory of this explosion is that the fine powdered coal that is in suspension in the air and lying against the sides of the workings and airways, contains in the little particle of dust the marsh gas. Each little particle of dust is assumed to be a little globule or balloon containing its fill of gas. These tiny particles lie so close together that they communicate instantly when they are shocked by the intense flame of the "Blownout Shot." This impalpable coal dust is everywhere in a dry mine, and a large volume of air circulating through the mine absorbs whatever moisture there may be in the mine dust and carries this moisture from the mine. This is particularly true in the winter time when the air is drier than in the summer. It has been observed that most of the very disastrous mine explosions of recent years have occurred in the winter. The conclusions of many mining men have been that these explosions were due to coal dust. Often after the explosion, the exploring parties have traced the explosion to its origin in a "Blownout Shot."

The coal dust in the mines is not dangerous with the flame of the miner's lamp nor is it injurious to his health when breathed in a well ventilated mine, but, with the powerful explosives now in use, great care must be exercised in shooting down the coal.

When this dust is prevalent and the mine is dry a system of moistening the intake air should be adopted to minimize the danger of coal dust explosion.

Questions on Chapter VI

How do you find the speed or velocity of the ventilating current?

What instrument is used to determine the resistance?

One inch of water gage equals how many pounds pressure per square foot?

What is understood by coefficient of friction, k?

How do you find the theoretical water gage?

What is meant by ksv^2?

What is the result if wrong coefficient of friction is used?

Describe the Pitot Tube and tell under what conditions it is most useful.

How does the force or power required to move vary with reference to velocity?

How does water gage, or pressure, vary with reference to velocity?

What causes the greatest difficulty in mine ventilation?

How should the excavation for an overcast be made?

What dangers arise from the presence of coal dust in a mine?

What should be done to minimize danger from coal dust explosions?

What may ignite coal dust?

CHAPTER VII

EARLY METHODS OF MINE VENTILATION

We can best appreciate how we are making progress by looking backward to our past.

When we stand beside a modern ventilating plant at a well equipped mine, we can admire its mechanical perfection and think of the beneficial work it is performing, but we will admire it all the more if we only know what went before it and how the art and science of ventilation have developed from their crude beginnings.

The early mines being mostly out of doors, were ventilated by the wind. When the workings went so far under the ground that the wind would no longer take care of them, some method of ventilation had to be devised.

VENTILATION BY DIFFERENCE IN ALTITUDE

The earliest method seems to have been an air shaft sunk into the workings some distance from the mine entrance. This method is usually termed natural ventilation. This is not strictly correct, for natural ventilation only applies to mines that are driven through a hill when one of the openings is of higher altitude than the other. It is not natural ventilation for the shaft is a device to take advantage of the difference in temperatures of the mine air and the atmosphere on the outside of the mine.

VENTILATION BY RAREFACTION

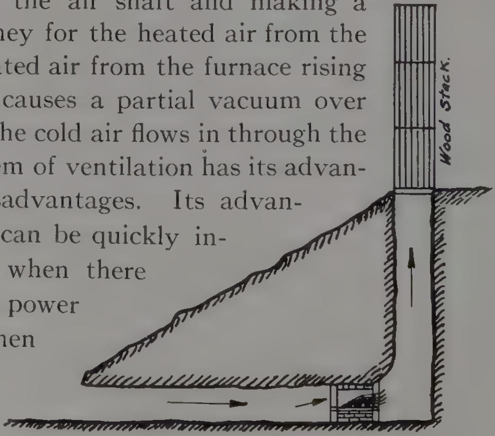
It is a well known law of nature that air that is heated above the surrounding atmosphere will rise. It was an observed fact that the air in an ordinary coal mine close to the earth's surface is above 60 degrees Fahrenheit. If the atmosphere surrounding the mine is below 60 degrees, the air will flow into the mine and out of the shaft, assuming the altitude of the intake to be the same as the bottom of the shaft. If the atmosphere is above 60 degrees, the air will flow down the shaft and out of the mine mouth. The rate of flow being proportional to the difference of temperature of the mine air and the surrounding atmosphere. Now, it is obvious that if the temperature of the atmosphere is the same inside the mine and outside there will be no flow of air through the mine. The air in the mine becomes stagnant on those days that have a temperature of 60 degrees. There are many such days. The results of this ventilation were not at all satisfactory so, some other method must be devised or the mines could work only on days of extreme temperatures.

It was observed by the early miners that it was the heated air that arose out of the shafts so the next step in the development was to create heated air at the bottom of the shaft. This was a simple process. The coal to furnish the heat was there. A basket of iron was devised to hold the burning coal and placed in the bottom of the shaft. The atmosphere flowed in to take the place of the heated air that had ascended the shaft and now we have a ventilating current going through the mine. Quite simple we will say, but mines were in operation centuries before this was done. The first record we have of this method of ventilation is in 1686, only two and a quarter centuries ago. It is in use in many small mines throughout the United States and Canada even today.

DEVELOPMENT OF VENTILATION BY FURNACE

This basket in the shaft led to the furnace ventilation. Furnace ventilation is still in operation in some mines, so we may briefly discuss it.

The furnace is essentially a set of grate bars on which the coal required to produce the necessary heat is burned. These grate bars are usually set in a fire brick casing, so that the fire may not destroy the brick work and communicate the fire to the surrounding coal. It is very necessary that this furnace be built with care as a scattering of the fire is likely to set fire to the surrounding coal and make a mine fire that is very difficult to put out. The furnace is usually placed at or near the bottom of the air shaft which is the extreme end of the return of the ventilating current. The air flowing through the furnace is heated and rises in the furnace stack which is usually the air shaft with a stack built over the air shaft and making a continuous chimney for the heated air from the furnace. The heated air from the furnace rising in the air shaft causes a partial vacuum over the furnace and the cold air flows in through the mine. This system of ventilation has its advantages and its disadvantages. Its advantages are that it can be quickly installed and used when there is no mechanical power obtainable and when the coal can be mined close to



Furnace and Stack

the furnace. It does not require an expert mechanic to attend to it.

DISADVANTAGES OF VENTILATING BY FURNACE

Its disadvantages are mainly: It can be used only to exhaust. It cannot be reversed. It is dangerous where there is "Firedamp." It furnishes an ever present danger of a mine fire unless the greatest care is exercised in caring for the cinders and ashes. It is, also, dangerous in case of neglect when the barometer and temperature are such as to make a reversal of the air current possible. In which case the smoke from the furnace getting the back draft is likely to circulate the air the wrong way and pass the smoke back through the mine. This action of the furnace may suffocate the miners before they can get out of the mine. At this time, its chief objection is in its waste.

Let us consider the furnace and its application to a mine. It is desired to pass 60,000 cubic feet of air per minute through a mine which will require one inch of water gage pressure. What height of stack will be required? The stack including the air shaft is the measure of the air column, assuming the intake opening to be at the same altitude as the furnace at the bottom of the shaft.

Assuming the barometer to be 30 inches and the temperature to be 60 degrees Fahrenheit, which is the usual assumption for such calculations, then the height h for the air column will be represented by the formula:

$$h = \frac{p}{w}$$

in which p is the pressure per square foot of the air at the given barometer and temperature and w is the weight of a cubic foot of air under the same conditions.

The formula then becomes

$$h = \frac{5.2}{.076} = 68.4 \text{ feet}$$

So that we will require a stack 68.4 feet high to produce a pressure as represented by one inch of water gage.

In an ordinary mine furnace it requires about one pound of coal per hour to raise the temperature of the air 12 to 15 degrees F. for each 1,000 cubic feet of air passing through the mine. If we represent the weight of coal required for our problem by w and the quantity of air by q and the rise in temperature necessary to produce the required pressure by T and the constant temperature by t we have the equation:

$$W = \frac{q \times T}{1{,}000t}$$

and inserting specific values we have:

$$W = \frac{60{,}000 \times 200}{1{,}000 \times 15} = 900 \text{ pounds}$$

Nine hundred pounds per hour. This consumption would be required during, at least, ten hours of the day and would represent nine thousand pounds, or four and one-fourth tons of coal, which at the present value of coal would make a furnace ventilation for such requirements very expensive.

We have referred to the grate as the essential feature of the furnace. What grate area would be required to burn the 900 pounds of coal per hour of the above problem? The rate of burning the coal on a given grate depends very much on the quality and hardness of the coal. In the ordinary bituminous mine, about 25 pounds per hour can be burned per square foot of the furnace grate. As we must burn 900 pounds per hour and 25 pounds is the amount burned per square foot of grate surface. The surface required will be found by dividing 900 by 25 which is 36 square feet. This would require a furnace 6 foot wide using a 6 foot grate bar.

VENTILATING WITH THE WATER SPRAY

About the same time that the furnace was devised for the ventilation of mines another means was used, which to us in these days seems strange. This was a spray of water dropped down the air shaft to cool the air in the shaft. Instead of heating the air in the shaft like the furnace, the spray of water cooled the air and caused the air to be forced through the mine. This method could only be used when the water could run away freely. But, as many of the early mines had an adit or tunnel to carry away all the water from the mine, this method worked well for those mines. It was in use until the mines got so deep that pumping became necessary for all the water accumulating in the mines.

VENTILATING WITH THE STEAM JET

With the advent of the steam engine for pumping the water from the mines came the steam jet for ventilation. The steam was handy. Very often the steam pipes were carried down the ventilating up cast shaft to the pumps, and the heat from the pipes gave rise to some ventilation. No doubt, it was discovered at some time through a leaky pipe in an up cast air shaft that the steam leaking caused a greater flow of ventilation and the steam jet followed. The steam jet not only heated the air in the up cast shaft, but through the velocity of its escape, it acted as a syphon to the ventilating current, adding velocity and momentum to the air column. The steam jet was so favorably considered in the early part of the nineteenth century, that the British Parliament recommended its use against other appliances of the period.

It had a short life, however, and this method of ventilation gave place to others more economical and effective.

It was the practice in the early days of mining to pass all the air entering the mine in one continuous current through the mine to the single outlet. This practice was possible when the mines were small and the volume of air was small in proportion. In some of the large mines in England, it is recorded that in the beginning of the nineteenth century, 5,000 feet per minute was the total volume. The airways were from 30 to 40 feet area. The velocity less than 200 feet per minute. With the furnace or steam jet, it would be difficult to get a large volume through such small airways when they were long and tortuous. The relief from this was the splitting of the air, making more airways and more inlets and so keeping the air in one or more ventilating currents until near the furnace or steam jet. This method of splitting the air and working the mine in panels was introduced in about 1840 and was generally in use shortly afterward. Through this device and the better care given to ventilation the volume of air passes through the mines rose rapidly until in many mines it reached a volume of upwards of 400,000 cubic feet per minute. With these large volumes, the furnace and steam jet were too expensive to operate and these devices gave way in the better managed mines to the fan.

Questions on Chapter VII

How can you ventilate a mine by difference in altitude?
How is a mine ventilated by difference in temperature?
Describe the furnace for ventilation.
Give the advantages of furnace ventilation.
Give the disadvantages of ventilating by furnace.
What is the theory of ventilating by water spray?
What was the effect of splitting the air?

CHAPTER VIII

DEVELOPMENT OF THE MINE FAN

The earliest fans we have record of are those used in ancient Egypt. They were a sort of paddle suspended from the ceiling of a room by a hinge. They were moved by two ropes. A slave on each rope pulled the fan alternately back and forth and stirred up the air in the room, thereby, making things more comfortable for the master of the house. We have no records giving the exact time of the change of this single bladed fan to numerous blades which constituted a wheel that could be revolved. In the process of development this came about. The earliest use of a fan for ventilating a mine that the author has been able to find a record of was in 1621. George Agricola records the use of a fan for ventilating a metal mine in Germany in that year. The arrangement is found figured in his work entitled "De Re Metalica." This fan was described as forcing the air into a mine whereas all furnaces and steam jets exhausted the air from the mine. The earliest use of the fan in England was an air pump rather than a fan. It was introduced by Struve. It consisted of two double acting aerometers twelve feet in diameter with stroke of from four tc six feet. The machine was a direct acting pump and was not depending on centrifugal action as a fan. This air machine gave place to the centrifugal acting fan.

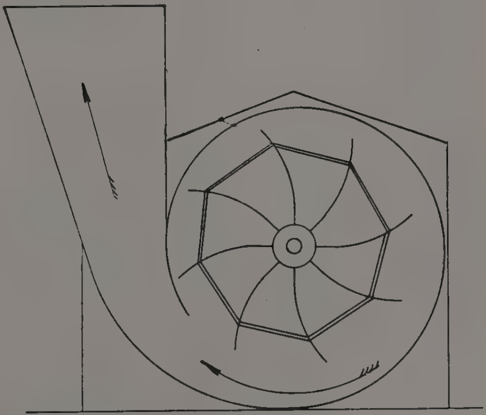
THE FIRST CENTRIFUGAL FANS

About the same time as Struve was introducing his aerometer, Brunton introduced a centrifugal fan which was placed immediately over an air shaft with the wheel horizontal and the spindle vertical. This fan was a true type and was operated to exhaust the air from the shaft.

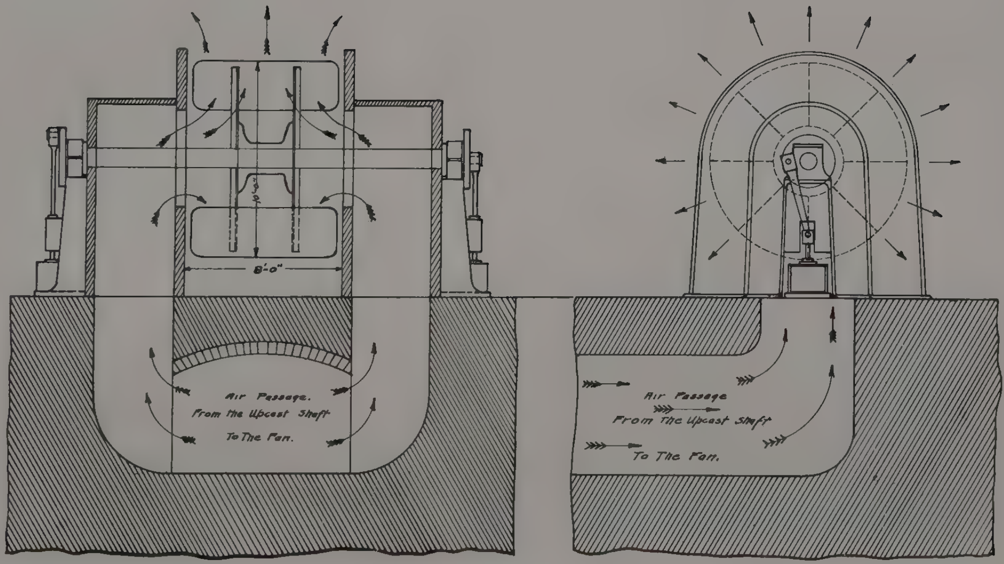
Shortly after the fan introduced by Brunton in 1851, a vertical wheel centrifugal fan was introduced by Nasmyth, the spindle being horizontal and the wheel vertical. The intake to the fan on both sides were connected to the top of the air shaft and the suction of the fan exhausted the air from the mine and discharged it from the periphery of the wheel. There being no casing about the wheel. This fan was connected directly to the steam engine which operated it. The engine crank being attached to the end of the fan shaft. This Nasmyth fan with the exception of casing about the wheel was a forerunner of the modern mine fan.

THE GUIBAL FAN

Shortly after the introducing of the Nasmyth fan, M. Guibal of Mons, Belgium, invented the spiral casing, shutter and evase chimney. This invention brought the modern fan up to its modern form except with relation to the wheel and its form and number of blades. Since M. Guibal's invention, the improvements



Guibal Fan



Nasmyth Exhaust Fan

and developments in mine fans, have been on the wheel or the rotor.

Up to this invention and including it, all the fan wheels were constructed with flat paddle blades. Guibal used the flat paddle blade but he set his blades with an angle backward to the direction of rotation. This form of blade has been almost universal in fan construction until very recently.

These early fans were constructed with a shaft or spindle on which were hubs of cast iron containing arms to which the wooden blades were attached. The casing was of wood. Owing to the construction and the diameters of these fans and moreover, to the fact that a steam engine was directly connected to them, they, of necessity, rotated slowly. They were built in large diameters as large as 60 feet frequently. With these fans, when a larger quantity of air was required at a mine than the fan in use could produce, it was thought only necessary that a larger fan be installed.

The science of the flow of air was not considered sufficiently to show the fallacy of such practice.

About the same time that Nasmyth and Guibal were introducing their fans, numerous other makers were designing fans that held their place for a time. The most noteworthy of these were Waddle and Schiele. Waddle's fan was similar to Nasmyth's in having no outer casing. Schieles was similar to Guibal's in having a spiral casing which was developed to suit a peculiar curve, which curve came to be known as the "Schiele Curve."

STEEL USED IN THE CONSTRUCTION OF A MINE FAN

In 1869 a patent was granted in England to John Lloyd for an improved fan. This fan was constructed of steel.

Its wheel consisted of a series of long and short blades. The long blades extending from the periphery of the wheel towards the spindle about half the distance. The short intermediate blades extended from the periphery of the wheel toward the spindle about one-third of the distance. The blades were all a segment of a circle set backward at the periphery as to the direction of the rotation. The wheel was enveloped by a series of curved plates attached to the fan wall. These plates were hinged so that the spaces between them might be increased or decreased at the pleasure of the operator. This was accomplished by means of a screw on the end of each of the curved plates. It will be noted that this fan had no spiral casing as the Guibal fan but discharged its air through the port openings of the curved plates directly into the atmosphere. This fan as patented was never extensively used. The wheel, however, with the blades curved in the direction of rotation, that is the opposite way to those of the original patent, is very extensively used in America today.

From the middle of the nineteenth century until the latter part, there was little change made in fan construction. It seemed to have settled down to empirical formula. The data for which was obtained from previous fan construction. Owing to the development of the mechanic arts, however, wooden fans began to give place to steel construction.

THE CAPELL, A DOUBLE INLET FAN

In 1884, Capell developed and patented in England, a steel fan having all its blades attached to hubs at the fan spindle and extending to the periphery. Each pair of blades making a complete compartment between them. This fan was a double inlet with a diaphragm of steel extending from the spindle to the periphery and completely separating each half of the wheel, which in effect made two complete fans on one wheel. In the previous fans the blades were paddles on the periphery of the wheel extending about one-third of the distance toward the spindle. The fan wheel was open on both sides to the air as it passed through the orifice of the casing. There was no diaphragm separating the wheel into two parts. The air entering the wheel of a fan of the Guibal type, could pass from one side to the other. The mingling of the two intake currents from each side of the fan caused eddies in the fan wheel, there being nothing to properly direct the incoming currents.

The Capell fan wheel was so constructed as to greatly eliminate these eddy currents and as it was substantially constructed of steel, it was capable of a high speed. A small fan of this type, running at a high speed could develop a high water gage and a large volume of air. This fan was highly successful. It made ventilation possible in mines that could not be ventilated by the slow rotating Guibal fan. It became extensively used wherever high water gage and large volume were necessary. It was the most successful fan known about the beginning of the present century. Its limitations were that its orifice of intake was small in proportion to its diameter and its volumetric capacity was low owing to the construction of the blades.

DEVELOPMENT OF HIGH PERIPHERAL SPEED FANS

In 1881, the author recalls seeing a fan in operation on the Buffalo mine near Courtney, Pa., which was known as a Murphy fan. This fan had a very large orifice. The blades were numerous and were only on the periphery. They extended toward the spindle about one-eighth of the distance leaving the center of the fan entirely clear of blades. This fan was run at a high speed, but as it was constructed of light material, it required frequent repairs. The mine it was ventilating was an old mine with long and very small airways. This mine must have developed a very high water gage with a small volume of air, and consequently the fan failed to furnish the desired ventilation. At that time very few mining men knew anything about the scientific ventilation of mines and in consequence, of their want of knowledge, this fan was condemned. This fan, would no doubt, have been successful on a mine less difficult to ventilate as it was typical of many fans that are in successful operation at this time. At many other mines this Murphy fan was very successful.

Questions on Chapter VIII

For what purposes were fans first used?
Describe the first centrifugal fan.
How were the blades set in a Guibal Fan?
Describe the fan constructed by John Lloyd.
Who developed a double inlet fan?
What were the limitations of the Capell Fan?
What was accomplished with the development of a high peripheral speed for fans?

CHAPTER IX

MODERN MINE FANS OF RECENT DEVELOPMENT

About the beginning of the present century a fan was developed in Belfast, Ireland for use of blowing furnaces, but it has been extensively used since to ventilate mines. It is known as the "Sirocco." This fan like the Murphy fan consists of numerous small blades only on the periphery extending toward the spindle about one-sixteenth of the distance. It has a very large orifice. It is built of steel and is capable of very high speed and has large volumetric capacity, and is capable of developing a high water gage. Owing to its large volumetric capacity, a small fan run at a high speed can deliver a large volume of air at a high water gage.

This fan is now extensively used in the mines of Great Britain and America. It is also used for ventilating buildings and blowing furnaces.

EXPERIMENTS OF ROBINSON WITH GUIBAL FANS AND DEVELOPMENT OF TURBINE

About the same time that the Sirocco fan was developed the author was experimenting with the Guibal fan and modifications of it. The idea being to make a very substantial wheel and at the same time increase the volumetric capacity, so that a small wheel could deliver any desired volume by regulating the speed. The results of these experiments led to what is known as the "Turbine" fan.

This fan consists of a wheel with three or more blades continuous from the spindle of the fan to the periphery and between these long blades there are numerous short blades extending from the periphery, toward the spindle about one-fifth of the distance. The blades are all attached to a diaphragm plate that in turn is attached to two truncated cones which are attached to the spindle. This construction is very substantial. It permits the wheel to rotate at very high speeds, and is capable of very high water gages and large volumetric capacities.

The Turbine fan is now recognized as a standard and is used very extensively in the coal mines of America. It is also used for blowing boiler furnaces and ventilating buildings.

REVIEW OF THE STAGES IN THE DEVELOPMENT OF FANS

The development of the mine fan was made in several different stages. First, was the Nasmyth type with the air exhausted from the mine through the fan and discharged from the tips of the blades directly into the atmonphere. Nasmyth thought that only an exhaust fan was practical in the ventilation of a mine for he says in his autobiography—"But in all cases in which this system of *forcing* air through the workings and passages of a mine has been tried, it has invariably been found unsuccessful as a means of ventilation." When the engineer learned more about the laws governing the flow of air through the mine, he found this statement of Nasmyths to be founded on a lack of knowledge.

The second stage was the spiral casing developed by Guibal. This is a very important stage. The discharge of air from the periphery of the wheel into the atmosphere direct without the casing was very wasteful of power. It will readily be seen by the reader that the exhausted air leaving the fan wheel at the velocity of the tips of the blades would fly in all directions disturbing the atmosphere to a great distance all around the fan. This agitation of the atmosphere required a large amount of power, with no return in the ventilation of the mine. Just as eddy currents within an enlarged space in the mine cause loss of power without adequate return in the ventilation. With the use of the spiral casing, Guibal caused the air leaving the tips of the blades of his fan to agitate only the air lying within the casing and the speed of the air within the casing was gradually reduced from the tip speed of the fan to near zero speed of the atmosphere when exhausting through the evase chimney. This was a very important contribution to the development of the fan, as it brought the mechanical efficiency of the Guibal fan to more than double the efficiency of the Nasmyth type.

The third stage was the development of the steel wheel and curved blades. This was accomplished by Lloyd and Capell. Through their efforts the wheel was made substantial, so that it could be run at high speeds, without flying to pieces. Lloyd's efforts were not so successful as Capell's because he did not use the spiral casing developed by Guibal and Capell did use it. The wheel developed by Lloyd was a better wheel to pass the air through it than was Capell's but it was not so substantially built, and neither of these inventors understood the value of curving the blades forward in the direction of rotation.

The fourth and last stage in the development of the modern mine fan was the enlargement of the intake orifice to the greatest extent possible and the curving forward of the blades in the direction of rotation. This was experimented upon and accomplished about the beginning of the present century by the inventors of the Sirocco fan and the Robinson Turbine fan. The author is not familiar with the experiments of the Sirocco to determine the limitations of these factors of the orifice of intake and the pitch of the forward curve of the blades but he is familiar with the development of the Turbine fan.

WHERE CUSTOM ALMOST OVERCAME PHYSICAL LAWS

It was the custom ever since Guibal set his flat paddle blades at a retreating angle to the direction of rotation to make all fan blades assume the same position. This was the case whether the blades were flat paddle or curved. Lloyd's fan and Capell's fan both had curved blades of steel but they copied Guibal's ideas with respect to the blades retreating from the direction of rotation. The author can recall when first entering the fan business that he made very diligent inquiry of many mining engineers and manufacturers as to why the blades would have this position and the only reply obtainable was that the blades should have such position so they pushed or rather wedged the air out of the wheel and into the fan casing. When the experimenting began to assume a really scientific form when records of various blades were taken under exact conditions, it was found that the best results were obtained in the first experiments with blades that were nearly flat and lying in a radial direction. That is, they had neither forward or backward curves. After making a number of these tests, we conceived the idea that a forward curved blade would make more air and give greater velocity than anything we were trying and we argued that the air passing along the blade from the center of the fan to the tips of the blade would get not only a centrifugal action from rolling along the blade, but, would have a tangential action due to the rotation of the wheel. The particles of air leaving the tips of the blades would also have a motion that was the resultant of those two forces so that by using the diagram of the parallelogram of forces, it could be graphically proved that the resultant speed of the air with a forward curved blade would be greater than with either a straight blade or a retreating curve.

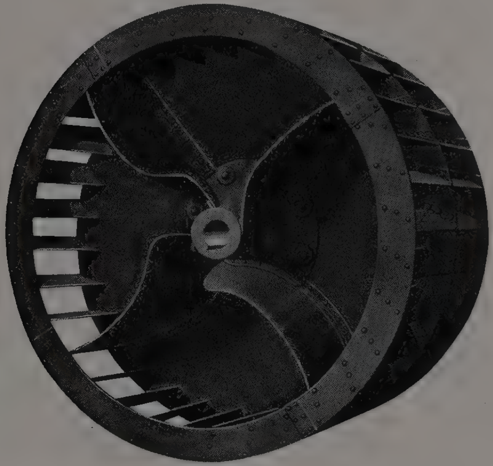
THE FORWARD CURVED BLADES INCREASE CAPACITY

We acted upon this idea and a set of forward curved blades were made and tried out. While they were being made, there was considerable sport made of the idea. Who ever heard of such a thing? Were not all fans made with retreating blades? The air required a retreating curved blade to get behind it and force it out of the wheel. The forward curved blade would cut into the air and hook it back into the wheel and discharge it through the intake orifice. These predictions were made by nearly all the workmen. When the wheel was tried out we could scarcely believe our results. They were astonishing. We had considered a volumetric capacity of one hundred per cent on the old style fan as a very good record, now, we were confronted with four hundred per cent. The speed of the air leaving the fan had increased nearly fifty per cent, showing this fan capable of working against much higher water gages than our old fans when running at the same peripheral speeds.

It was necessary then to experiment with the forward curves until a definite angle should be developed that would give the greatest velocity to the air in proportion to the tip speed of the blades. This we determined after many experiments. The wheel finally came to such form that it consisted of a spindle on which were mounted two truncated cone castings, which were placed with their bases together with a circular plate of steel between, this circular plate being the exact diameter of the wheel. To the cones and the circular plate of steel the large blades running from the periphery of the wheel entirely down to the hubs were attached. The small blades were attached to the circular plate of steel and to an outer ring which was the same diameter as the middle plate. These outer rings were also attached to the large blades making a box-like, secure and substantial wheel capable of great speeds without danger of disruption.

THE CENTRIFUGAL FAN OF MODERN MINES

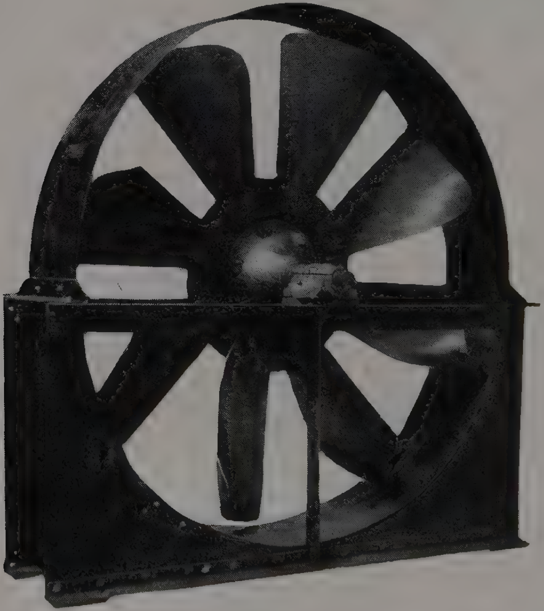
That the reader may better comprehend the developments of the centrifugal fan, it may be well to discuss the action of this fan in general. A centrifugal fan consists of a series of blades so arranged with reference to a spindle that they form a wheel which may be rotated on its spindle. The rotative motion of the blades causes the air lying along the faces of the blades to roll or slide along the faces from the spindle toward the tips of the blades. This displacement of the air about the center of the wheel causes a partial vacuum in the interior of the wheel which in turn causes the atmosphere to flow into the wheel to restore the equilibrium. This action, if continued causes a current of air to flow into the fan wheel at its center or intake and flow out of the wheel at its periphery. In so doing the air passes through a right angle and describes a spiral, entering the wheel parallel to the axis of rotation and passing out of it at right angles to the axis of rotation. The wheel being in motion, the particles of air describe a spiral. The casing about the wheel directs the current of air that is discharged by the fan into whatever direction it may be desired to take.



Turbine Fan Wheel

THE DISC OR SCREW PROPELLER FAN

The foregoing discussion applied to the centrifugal fans. The disc or screw propeller type is a fan used to a great extent in small mines and for auxiliary purposes. This type consists of a spindle mounted on a pair of bearings with the casting attached to the spindle to which blades are attached, this constituting a wheel, the blades are encased by a casing concentric with the wheel. They are usually set at an angle of 30 degrees with a plane passing through the axis of rotation. When the blades are flat, this type of



Modern type Disc Fan

fan can be readily reversed simply by reversing its motion.

The fan is usually placed in an airway with its spindle parallel to the airway. The casing is bratticed around to the sides, floor and roof of the airway so as to make all the air current go through the wheel of the fan. The action of this fan is to pass the air through the wheel parallel to the axis of rotation. The blades of the wheel, due to their angularity and to the rotary motion, push the air forward or backward depending on the direction of rotation. But, there is a certain amount of centrifugal action to the rotary motion of the wheel and this action causes a large amount of the air that should go forward to be thrown against the fan casing at nearly right angles to the path of the forward moving air. This centrifugal action set up eddy currents within the fan and creates a partial vacuum in the center of the wheel. The air, to restore the equilibrium, rushes in from all sides to the center of the wheel and greatly reduces the fan's efficiency. Under great mine resistance, this action is so injurious as to destroy the fan's usefulness and then the centrifugal fan must be used to replace the disc. This type of fan is useful to ventilate small mines or as an auxiliary in a side heading where the pressure is light. Owing to the low mechanical efficiency of this fan, it is not used where large volumes are required, and it is unable to work against a high water gage.

Questions on Chapter IX

What was the theory involved in the construction of the "Sirocco" Fan?

Give Nasmyth's theory of mechanical Ventilation.

What contribution to fan development was given by M. Guibal?

What were the contributions of Lloyd and Capell?

Who conceived the idea of an enlarged intake orifice?

Why could fans with blades set at a retreating angle not develop a great volumetric capacity?

What results were secured by the forward curved blades?

Describe the inlet and outlet of a centrifugal fan.

What do we understand by the term, disc fan?

How should a disc fan be put on a mine?

How is the flow of air through a disc fan as compared with a centrifugal?

CHAPTER X

EFFICIENCIES OF VENTILATING MACHINES AND ORIFICE OF PASSAGE

It is customary in discussing mine fans to speak of the efficiency of the fan. We usually think of the mechanical efficiency when we use the term efficiency. There are other efficiencies that must be considered. The mechanical efficiency is the relation of the work done by the fan upon the ventilating current to the power expended upon the fan. This does not take into consideration the efficiency of the engine or motor used to drive the fan but is simply the power applied to the fan shaft. Often the fan is directly attached to the engine or motor, and the total input of the power to the engine or the motor is charged against the total output of the fan upon the ventilating current and the result is known as unit efficiency. When the fan is belted or geared, the efficiency of the fan alone is considered. The mechanical efficiency of the unit is usually expressed by the formula:

$$\text{Mech. Eff.} = \frac{\dfrac{q \times w\,g \times 5.2}{33{,}000}}{\text{Input } H.\,P.}$$

To illustrate this let us take for example a mine passing 132,650 cubic feet of air per minute at a static water gage of 3.85 inches. The indicated horse power of the engine being 105.33 H.P.

$$\text{Mech. Eff.} = \frac{\dfrac{132650 \times 3.85 \times 5.2}{33{,}000}}{105.33}$$

$$= 76.4 \text{ per cent}$$

This example is for a steam engine driven fan with an indicated horse power of 105.33 when the engine is direct connected. The mechanical efficiency is therefore unit efficiency. If the fan is belted to the engine and the fan efficiency alone is desired then the usual allowance of loss for the belt is ten per cent of the power applied to the steam engine.

When an electric motor is used to drive the fan, the input current of the motor is used instead of the indicated horse power of the steam engine. The formula then becomes:

$$\text{Mech. Eff.} = \frac{\dfrac{q \times w\,g \times 5.2}{33{,}000}}{\dfrac{\text{voltage} \times \text{amperes}}{1\ \text{Watt} \times \text{Motor Eff.}}}$$

This formula holds good for only direct current. For alternating current there are many other factors to be considered.

A mine is passing 85,000 cubic feet of air per minute at 3.5 inches (static) water gage. The fan is driven by an electric motor D. C. and is consuming 236 Volts and 174 Amperes. The motor is rated at the above load as 90 per cent efficient. What is the mechanical efficiency of the unit? The motor is belted to the fan:

$$\text{Mech. Eff.} = \frac{\dfrac{85{,}000 \times 3.5 \times 5.2}{33{,}000}}{\dfrac{236 \times 174}{{}^{*}746 \times 90}} = \frac{46.88\ H.P.}{61\ \ \ H.P.}$$

$$= 76.69 \text{ per cent}$$

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*746 Watts equal one horse power.

If the unit efficiency is 76.69 per cent, what is the mechanical efficiency of the fan alone? The motor loss has already been accounted for, assuming the loss due to the belt to be 10 per cent of the input, the efficiency of the fan alone would be 85.4 per cent.

When alternating current is used, there are a number of factors so indeterminate that it is best to use a watt meter to obtain the horse power actually used during a given period. This method makes the records average well and evens up the fluctuations of power.

THE MANOMETRIC EFFICIENCY OF A FAN

The manometric efficiency of a fan is the ratio that the actual water gage bears to the theoretical water gage.

The theoretical water gage is obtained from the following formula:

$$E = \frac{\frac{(D \times \Pi \times R)^2}{60}}{g} \times \frac{1.2}{1,000} \times 12$$

In which D is the diameter of the fan wheel, Π is the ratio of the circumference to the diameter of the circle, R is the number of revolutions of the fan, and g is the force of gravity, $\frac{1.2}{1,000}$ is the ratio of weight of air to that of water and 12 the number of inches in a foot and 60 the number of seconds in a minute.

Let us take an actual running fan, 6 feet diameter running 235 R.P.M., the actual static water gage being 1.87 inches, and determine its manometric efficiency using the formula we have:

$$E = \frac{\frac{(6 \times \Pi \times 235)^2}{60}}{32.16} \times \frac{1.2 \times 12}{1{,}000} = 2.44 \text{ inches}$$

The theoretical water gage is 2.44 inches and the actual water gage is 1.87 inches. The manometric efficiency would therefore be $\frac{1.87}{2.55} = 73.3$ per cent.

VOLUMETRIC CAPACITY OR RATIO, AS APPLIED TO FANS

The volumetric capacity of the fan is its capacity to pass air through itself in proportion to the cubic contents of the wheel and the number of rotations. The formula for determining the volumetric capacity of a fan is:

$$C = \frac{q}{\left(\frac{D}{2}\right)^2 \times \Pi \times W \times R}$$

q represents the quantity of air in cubic feet per minute, D represents the diameter of the fan in feet, Π is the ratio of circumference to diameter of circle, W represents the width of the fan in feet, and R represents the revolutions of the wheel per minute.

The volume of air passed by a fan with a wheel 4 feet 9 inches in diameter and with a 3 foot face is 116,000 cubic feet per minute. The revolution of the wheel is 580. What is the volumetric capacity?

$$V.\ C. = \frac{116{,}000}{\left(\frac{4.66}{2}\right)^2 \times 3.1416 \times 3 \times 580} = 390 \text{ per cent}$$

The mechanical efficiency, manometric efficiency and volumetric capacity as discussed here apply only to centrifugal fans.

EQUIVALENT ORIFICE OR ORIFICE OF PASSAGE

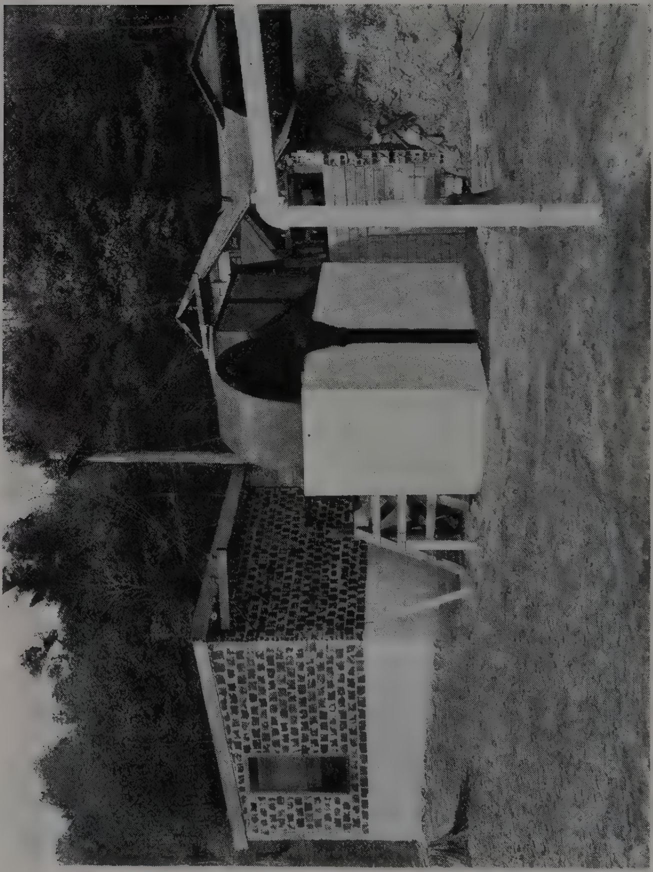
One of the factors in the installation of a mine fan that is often neglected is the Equivalent Orifice. Murgue, the engineer who determined the coefficient of friction which carries his name, made a large number of observations on mines to determine the equivalent orifice and from these observations he determined a formula which expresses the relation the volume of air passing through the mine bears to the static resistance as measured by the water gage. The formula is largely empirical, but it is useful for observation when installing a fan to suit existing conditions or in correcting these conditions. He expresses the velocity of flow through such an orifice as though the air were passing through a thin plate and applying the *vena contracta* of the flow as .62 of the velocity he deduced the formula:

$$A = .0004 \times \frac{q}{\sqrt{i}}$$

In which q is the quantity of air passing in cubic feet per minute, and i is the water gage in inches, A is the area of the orifice in square feet.

To illustrate the formula let us consider a mine that is passing 59,000 cubic feet per minute at a water gage of 1.87 inches. What would be the Equivalent Orifice of this mine? Applying specific values to the formula we have:

$$A = .0004 \times \frac{59{,}000}{\sqrt{1.37}} = 17.226 \text{ square feet}$$



Robinson Fan—Cherry Tree Coal Company

which is equivalent to the orifice in a thin plate through which 59,000 cubic feet of the example cited will pass at 1.87 inches water gage. When the actual water gage is obtainable, this formula shows the condition of the mine as to whether the resistance is normal or abnormal. There is a short method of approximating when the actual water gage is known. Take the speed of the air due to the pressure, from the table on page 67, apply the *vena contracta*, which is 62 per cent. The result will be the mean speed of the air. Now, to obtain the equivalent orifice of the mine, divide the quantity of air by the mean speed of the air.

In the example above, the pressure or water gage is 1.87 inches, which corresponds to a speed of 5,258 feet, 62 per cent of which is 3260 feet. The equivalent orifice with this method would be:

$$\frac{59{,}000}{3{,}260} = 18.1 \text{ square feet}$$

This method is quite accurate and works out nicely in practice.

The equivalent orifice of the mine leads to examining the orifice of passage of the fan and a comparison of the two will often lead to information beneficial to the ventilation of the mine.

The orifice of passage of a fan is a term used to describe the relation the air actually passing through a fan bears to what would pass through if the intake and discharge openings were unobstructed.

To make this more clear let us take an example of a fan actually in use. There is a fan with a wheel 4 feet 9 inches in diameter with a 3 foot face that is passing 116,000 cubic feet of air per minute at 5.4 inches water gage, running at a speed of 580 R.P.M. This fan has an intake orifice on each side of the fan that is 12.8 square feet area. The combined area is 25.6 square feet. The discharge orifice is equal to the combined area of the two intakes. What is the orifice of passage of this fan?

Using the usual formula for orifice of passage:

$$a = \frac{Q}{0.65 \times 60 \times \sqrt{2gh}}$$

In which a represents the area of the orifice of passage, Q the quantity or volume of air in cubic feet per minute, and h the head due to the water gage, we have:

$$a = \frac{116{,}000}{0.65 \times 60 \times \sqrt{2 \times 32.16 \times \frac{5.4 \times 5.2}{0.076}}}$$

$$= 19.29 \text{ square feet}$$

It has generally been regarded as good practice to have the intake orifice of the fan double the equivalent orifice of the mine. That, however, is empirical and does not hold good under all mine conditions. There are many other factors to be considered in the installation of the fan which are of more importance.

The fan referred to above is passing 116,000 cubic feet of air per minute against 5.4 inches of water gage. What is the equivalent orifice of the mine?

$$E.\ O. = .0004 \times \frac{116{,}000}{\sqrt{5.4}} = 19.97 \text{ square feet}$$

The equivalent orifice of this mine is 19.97 square feet and the orifice of passage is 19.29 square feet, which by using the different formula or orifice of passage of fan and equivalent orifice of mine, gives practically equal results.

The combined area of the two intakes of this fan is 25.6 square feet. If we apply the *vena contracta* to this orifice as 62 per cent the intake orifice would be 15.87 square feet which is less than the equivalent orifice of the mine or orifice of passage of the fan. If we apply the *vena contracta* as 82 per cent which is the latest practice for this type of orifice, we have an intake orifice of 20.99 square feet area.

With the empirical formula usually employed we should expect this fan to be wasteful of power. Let us examine the data taken in a test on this fan. The volume of air is 116,000 cubic feet, the water gage is 5.4 inches static, the actual reading of the watt meter is 95 K. W. or 127.345 horse power. Substituting in the formula for mechanical efficiency we have:

$$\frac{\dfrac{116{,}000 \times 5.4 \times 5.2}{33{,}000}}{127.345} = 77.5 \text{ per cent mechanical efficiency}$$

It would seem from this mine and the fan connected to it that the equivalent orifice of the mine and the orifice of passage should be nearly equal. One more example of a fan of a larger capacity, and then we will proceed to use the natural law which governs the flow of air, in order to determine the characteristics of the fan to suit the mine in question.

There is a fan with a wheel 8 feet in diameter and 4½ feet wide, passing 260,000 cubic feet of air per minute against a 5 inch water gage static. First, what is the equivalent orifice of this mine and also, what is the orifice of passage of the fan?

$$E.\ O. = .0004 \times \frac{260{,}000}{\sqrt{5}} = 46.51 \text{ square feet}$$

The intake orifices of the fan combined are 77 square feet. If we use the *vena contracta* of this orifice as 62 per cent, then the orifice would be 47.75 square feet. If the vena contracta is 82 per cent of the intake orifice then, the orifice is 63.14 square feet. In neither of these cases nor even in the case of the total intake orifice is the area double the equivalent orifice of the mine.

This fan is also very economical of power.

Questions on Chapter X

What is meant by the term mechanical efficiency?

State the formula for the mechanical efficiency of a fan.

What is the difference in calculating for a steam driven direct connected engine and for an electrically driven fan?

What is the manometric efficiency of a fan?

What is meant by volumetric capacity?

Who developed the formula for the equivalent orifice?

What is meant by the equivalent orifice?

What is the vena contracta in a problem as determined by Murgue?

CHAPTER XI

CHARACTERISTICS OF FAN TO MEET GIVEN CONDITIONS

To determine the characteristics of a fan to suit any given mine, it is necessary first to know the quantity of air to be passed and the actual water gage static and total head on which to base the calculations. The total head, which is the static water gage plus the velocity head is the basis for calculating the speed of the air. The velocity head is usually neglected in mine work because of the large airways used. But, when the airways are small, this velocity head cannot be neglected. With these factors of quantity of air and water gage known, we can determine the characteristics of the fan if its volumetric capacity is known. The usual method for the calculation of a fan for a given mine is to observe the water gage and quantity, or volume, using the observation as a base line for the calculation to follow. The natural laws governing the flow of air that must be used in these calculations are:

First,—The volume or quantity of air varies directly as the velocity of the air.

Second,—The pressure or water gage varies as the square of the velocity of the air.

Third,—The force or power required to keep in motion the ventilating current varies as the cube of the velocity of the air. It is of first importance.

WORK AND LIMITATIONS OF A MINE FAN

At this time let us remind the reader that the fan is only a machine to create a depression in the center of its wheel.

The air thrown off the tips of the fan blades causes the air to flow into the center of the wheel to replace the displacement and to restore the equilibrium. The fan, if blowing into the mine forces the air from the tips of the blades in proportion to the tip speed of the latter. If exhausting or sucking the air from the mine, the exhausting process is also in proportion to the tip speed of the blades. We have discussed the relation of the peripheral speed of the fan to the velocity of the air. This speed will now come into play in determining the diameter and revolutions per minute of the fan wheel. The fan wheel will therefore rotate in direct proportion to the speed of the air so that the tip speed of the blades shall be such speed as to give the impulse necessary to secure the speed of the air which creates the pressure or water gage. This tip speed is a product of the circumference of the wheel multiplied by the number of rotations. In determining the tip, speed there is a constant which must be used, which is the ratio of speed with which the air leaves the tips of the blades to the circumferential speed of the wheel. This ratio varies greatly with different types of fans. In some it is in excess of the tip speed and in others it is less than the tip speed.

Let us assume that the constant is 20 per cent in excess of the circumferential speed, the formula then for the velocity of the air leaving the circumference of the wheel would be:

$$V = (\Pi D + .20 \Pi D) \times N$$

In which V is the velocity of the air, D is the diameter of the wheel in feet, N is the number of rotations of the wheel and Π is the ratio of circumference of the wheel to its diameter. With the velocity of the air as shown in the table, we can transpose this formula to determine the number of revolutions of the wheel. The formula then becomes:

$$N = \frac{V}{(\Pi D + .20 \Pi D)}$$

The speed of the wheel determined, how can we determine the width? To obtain this dimension, we must know the volumetric capacity of the wheel and how this capacity changes under varying conditions of mine resistance. This can only be determined by observation, as it depends on the curvature of the blades, their number, and the angle of advance or retreat of the blades at the periphery of the wheel. These factors combined give the fan its characteristics of volumetric capacity. So that this feature of the calculation is necessarily empirical. It is different with each type of fan and even in the same type will vary with the mine resistance.

The periphery speed determined and the volumetric capacity assumed, how shall we determine the orifice?

THE INTAKE ORIFICE OF A FAN

The intake orifice should be determined from the speed of the air that is necessary to overcome the resistance or water gage of the mine.

In the discussion of the equivalent orifice of the mine and the orifice of passage of the fan, we discovered a certain relation between the two. Let us now discuss the intake orifice of the fan with reference to the speed of the air. We know from our tables what the speed of the air is for any given water gage and we know that the orifice of a fan is a thin plate. We can use our *vena contracta* for this and we obtain the area of the intake orifice. The formula for this is:

$$O = \frac{Q}{.62V}$$

In which O is the area in square feet of the orifice, Q is the quantity of air in cubic feet per minute, V is the velocity of the air due to pressure or water gage, and *.62* is the *vena contracta.*

SIZE OF DISCHARGE OR OUTLET FOR A FAN

The outlet or discharge of the fan casing should be the equivalent of the intake orifice as the air must pass through it at the same speed as through the intake. The orifice of passage of the wheel will be necessarily smaller than the intake orifice, for the wheel occupies considerable of the fan space within the fan casing, and moreover, the wheel is in motion, carrying the air around with it.

PERIPHERAL SPEED REQUIRED FOR A GIVEN PRESSURE AND VELOCITY

Let us now determine the periphery speed of a fan wheel required to produce 5.4 inches water gage. The velocity of the air due to the pressure is, for 5.4 inches of water gage, 9,240 feet per minute. Assuming 20 per cent as the constant excess of speed of air over the periphery speed of the wheel and arbitrarily assuming the diameter as 4 feet 9 inches, we have in formula:

$$N = \frac{V}{(\Pi D + .20 \Pi D)} \qquad \text{substituting}$$

$$= \frac{9{,}240}{\Pi \times 4.75 + (.20 \times \Pi \times 4.75)}$$

$$= 516 \text{ Revolutions}$$

We find that 516 R.P.M. will create the necessary depression to make 5.4 inches water gage with this fan.

Let us assume now, that the mine passes 116,000 cubic feet of air per minute when the water gage shows 5.4 inches. How wide should a wheel be that is 4 feet 9 inches in diameter, running at 516 R.P.M.? The area of a 4 foot 9 inch circle is 17.72 square feet. Assuming that for this type of fan the volumetric capacity is three hundred per cent. The wheel would then discharge at each revolution 17.72 × 3 or 53.16 cubic feet and for 516 revolutions it would discharge 53.16 × 516 or 27,431 cubic feet for each foot of width, and as the quantity to be discharged is 116,000 cubic feet, the width of the fan wheel should be $\frac{116{,}000}{27{,}431}$ or 4.23 feet. Having determined the diameter and the width of the wheel and its number of rotations, let us see if we have a large enough intake orifice. The intake orifice of a 4 foot 9 inch wheel has 12.8 square feet area. Will the air pass through this opening at the pressure of 5.4 inches water gage?

Remembering that the speed of the air is 9,240 feet per minute for 5.4 inches of water gage and the *vena contracta* is 62 per cent, the mean speed of air through the opening could be only 5728 feet per minute, and the quantity that could pass through an opening 12.8 square feet would be 5,728 × 12.8 or 73,318.4 cubic feet. It is evident that if the fan were a single inlet, the required volume could not be passed at the given water gage, but if it were a double inlet fan, then the quantity 73,318.4 cubic feet could be doubled. 73,318.4 × 2 = 146,636.8 cubic feet, which proves that the intake is amply large for this particular instance when the volume is 116,000 cubic feet at 5.4 inches of water gage.

CONCLUSIONS ON A PARTICULAR FAN

We have found the wheel to be 4.23 feet wide. The width of the wheel determines the width of the discharge opening, and assuming there would be sixteen one-hundredths of a foot clearance between the wheel and the casing, the discharge opening would then be 4.3 feet wide. We have seen that the two intakes of this fan have an area of 25.6 square feet; the height, therefore, of the discharge opening should be $\frac{25.6}{4.3}$ or 5.86 feet. The spiral casing about the wheel should be made to conform to the discharge opening. The example above shows a fan designed to suit certain conditions of the mine and being fitted to meet the given conditions, the fan is efficient and economical.

MEETING ANOTHER CONDITION IN VENTILATION

Let us now consider a fan that is of a modern type but does not meet the conditions of the mine on which it is operating. The mine is passing 98,000 cubic feet of air per minute at 2.8 inches water gage. The fan is 16 feet in diameter and 6 feet wide. Let us consider the equivalent orifice of the mine first:

$$E.\ O. = .0004 \times \frac{98,000}{\sqrt{2.8}}$$

$$= 23.47 \text{ square feet}$$

Let us now consider this fan from the periphery speed and volumetric capacity.

It is 16 feet in diameter running at 130 revolutions per minute. It should be making a velocity of

$$V=(3.1416 \times 16 + 20 \times 3.1416 \times 16)\ 130$$
$$=7839 \text{ feet}$$

7839 feet per minute is equivalent to more than 4 inches water gage, whereas the fan is producing only 2.8 inches.

Now as to its volumetric capacity: This fan would be able to produce under suitable mine conditions, two hundred per cent volumetric capacity. It has a wheel 16 feet in diameter and 6 feet wide. The cubic contents of the wheel is 1206 cubic feet and at 130 revolutions it could produce 1,206 × 2 × 130 or 313,440 cubic feet per minute, yet it is only producing 98,000 cubic feet per minute, or a volumetric capacity of 63 per cent.

On this mine if the fan should produce 313,000 cubic feet on its present mine conditions the water gage would be:

$$(313{,}000^2) : (98{,}000^2) : : x : 2.8$$
$$X=\frac{(313{,}000^2) \times 2.8}{(98{,}000^2)}$$
$$=28.5 \text{ inches}$$

A FAN WHICH IS TOO LARGE FOR EXISTING CONDITIONS

It will be noted that the equivalent orifice of the mine is small, only 23.47 square feet, and the fan can produce a volume at the speed it is running far beyond the capacity of the mine under the present conditions. Needless to say, this fan is running very wastefully as to power and is also breaking itself to pieces in attempting to pass a larger volume through itself than the mine will take at the pressure the fan is capable of making at the given speed. The fan is too large for the mine.

The equivalent orifice of the mine should be greatly enlarged or a smaller fan installed to suit the mine conditions.

Owing largely to the empirical formula applied to the calculations of fans, we find many examples like the above. One of the greatest fallacies that we encounter in fan calculations is that the speed of the air at the intake orifice should never exceed 2,000 feet per minute. Why 2,000 feet per minute if the fan is producing a depression sufficient to create a greater speed?

The intake and discharge orifice of the fan should always be proportioned as the velocity of the air is to the pressure on the mine.

A fan is often wasteful of power when it is too small for the mine on which it is operating, owing to the orifice of passage of the fan being too small for the equivalent orifice of the mine.

CHANGING FANS TO MEET CHANGED CONDITIONS

A mine that was operating in a thin seam of coal was ventilated by a 14-foot Guibal fan. The volume of air was 60,000 cubic feet per minute at one inch water gage. A fall occurred in the main air course near the fan which was of such character that it was thought not practical to remove it and the Guibal fan, after this fall could force only 22,000 cubic feet per minute at one inch water gage through the mine. There was no other intake for the air at the time. It became necessary to install a fan that could pass 45,000 cubic feet per minute against new conditions occasioned by the partial closing of the intake airway. This new condition required a 4 inch water gage to pass the 45,000 cubic feet per minute and a fan was required that could overcome this pressure while making 45,000 cubic feet per minute.

The equivalent orifice of this mine is found from the formula: Substituting, we have:

$$E.\,O. = .0004 \times \frac{45{,}000}{\sqrt{4}}$$

$$= 9 \text{ square feet}$$

The fan chosen was a 3 foot, double inlet blowing fan whose intake orifices combined were 10.2 square feet. The width of the wheel was 2 feet 4 inches. Its speed was 600 R.P.M., motor driven by a 50 horse power motor. When delivering the 45,000 cubic feet per minute at a 4 inch water gage, it required a driving force of 40 horse power. The work performed was excellent and the mechanical efficiency was good. Some time after the installation was made the main air course was driven through the hill making a good intake possible at the rear of the mine. The fan was removed to the new opening and its speed remained the same. To the surprise of the management the volume of air increased to 54,000 cubic feet per minute and the water gage decreased to one inch. The fan was consuming 48 horse power in electric current. This new condition of the mine changed the fan from a unit efficiency of about 70 per cent to a unit efficiency of less than 18 per cent. What had caused this difference in economy when the motor and the fan were the same?

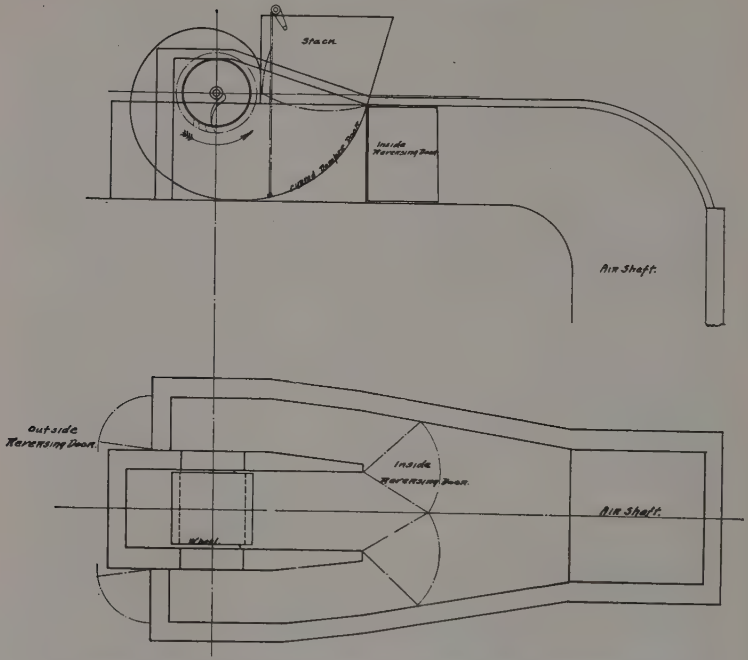
The equivalent orifice of the mine had changed from 9 square feet to 21.6 square feet while the orifice of passage of the fan remained the same. The orifice of passage of the fan should have changed as 21.6 is to 9 square feet and the fan would then have been 4½ feet in diameter instead of 3 feet. The change in the equivalent orifice of the mine required a change in the orifice of passage of the fan to suit the new mine conditions. The fan was suitable for the condition which required 45,000 cubic feet per minute at a 4 inch water gage. When, however, the conditions changed to 54,000 cubic feet per minute at one inch water gage, the fan could not meet those conditions because it must run at 600 R.P.M. to pass 54,000 cubic feet per minute, and when running at that speed it was creating a 4 inch water gage within itself, although the mine did not required so high a pressure to pass the 54,000 cubic feet per minute. The effect on power consumption was the same, as far as the fan was concerned, as though the mine required a 4 inch water gage to pass the 54,000 cubic feet per minute. The force in the air for 54,000 cubic feet per minute at 4 inch water gage is 34 horse power, and the power consumption being 48 horse power, the mechanical efficiency is approximately 70 per cent, which is good. This fan should have been replaced by a larger one to suit the changed conditions of the mine. As to its own performance, it was good even after the changed condition of the mine, but when the mine only was considered, in comparison with the power consumption of the motor, the failure to produce efficiency in the ventilation unit was charged to the fan.

This was erroneous, as the fan was designed for the original condition and not for the later condition of the mine.

DESCRIPTION OF A REVERSIBLE FAN

Sometimes it is desired to have a fan force the air through the mine, and at other times to have the air exhausted from the mine. If this double purpose is accomplished by the same fan, it is called a reversible fan. A reversible centrifugal fan is so constructed that the air can be drawn into the wheel from the mine or forced from the wheel into the mine, by a system of doors suitable, attached to side air chambers, and an exhaust stack. The cut taken

Reversible Fan



Reversible Fan, Showing Air Chambers, Stack and Reversing Doors

from the photograph will illustrate a reversible fan from the exterior showing its general arrangement and the line drawing will show the details and the manner in which the air currents are reversed in the mine by the manipulation of the doors in the air chambers surrounding the fan. The wheel of the fan is never reversed. In fact, it is erroneous to speak of the fans being reversed. It is the air current within the mine which is reversed. The air in the fan wheel always has the same direction. The manipulation of the doors in the stack and air chambers reverses the air current in the mine, but the current through the fan flows always in the same direction whether the fan is blowing or exhausting.

We often hear mining men complain that their fan works better when exhausting than when blowing, or the reverse. A fan may work better one way than the other due to some natural condition such as the angle of pitch of the coal seam or perhaps, the airways are of such nature that there is more friction encountered by the ventilating current in blowing than in exhausting, or vice versa.

DESCRIPTION OF A SPECIFIC CONDITION

The first of these conditions due to pitching seam is usually the reason why the ventilating current passes more readily one way than the other. Let us examine a mine with a pitching seam and study the causes underlying the flow of air. Let us assume for illustration, a mine with one outlet and one inlet for the air. The fan is on the opening which has the lowest altitude. Let us assume the temperature to be 80 degrees Fahrenheit. It is obvious that the air in the mine through its lower temperature than that of the outside atmosphere, will flow out the lowest outlet being the one on which the fan is placed. Let us assume the fan to be stopped. Then, the air flowing out through the fan would be taking the same direction as though the fan were operating as an exhaust fan. Now, if the temperature changes to say 40 degrees, then the air in the mine being of a higher temperature than the atmosphere outside, will flow in at the fan inlet, reversing itself and in the direction that the fan would take if the fan were blowing. The reversal of the ventilating current being caused by the change of temperature of the atmosphere outside the mine while the air within the mine remains at a constant temperature. In the one case, the temperature of the outside air being a positive and in the other case a negative quantity.

Now suppose that the fan be put in motion so as to operate on the air in the direction of its natural flow. The fan will not perform any work on the air until it increases the movement of the latter above its natural speed. But, should the air chambers and doors around the fan be changed to reverse the ventilating current against the natural flow, it is obvious that the fan will have to perform all the work of the ventilating current due to natural causes before the current is brought to a state of rest. If the fan reverses the ventilating current until the speed of the air is equal to the speed due to the natural causes, then the fan will have performed double the work necessary to propel the ventilating current in case there were no natural ventilation. Let us illustrate this by assuming a mine to have a natural ventilating current of 30,000 cubic feet per minute and that this quantity is passing at one half inch water gage. The atmospheric temperature outside of the mine is 80 degrees and the air is passing through the fan as an exhaust. The power in the air current is found to be:

$$H.\ P. = \frac{10 \times .5 \times 5.2}{11} = \frac{5 \times 5.2}{11}$$

$$= 2.36 \text{ horse power}$$

Now, should the fan be reversed, the atmospheric temperature remaining the same, it would require 2.36 horse power to bring the ventilating current to a state of rest. It would require 4.72 horse power to reverse the current to 30,000 cubic feet per minute. Should the temperature of the atmosphere without the mine, change from 80 degrees to 40 degrees, the above calculations would reverse themselves. Let us continue this investigation and assume that the fan propels the air in the same direction as the natural ventilation but that the quantity passing through the mine is 60,000 cubic feet per minute instead of 30,000 cubic feet per minute. The water gage being as the square of the quantity, the mine would be passing 60,000 cubic feet per minute at 2 inches of water gage and the power on the ventilating current would be:

$$H.\,P. = \frac{20 \times 2 \times 5.2}{11} = \frac{40 \times 5.2}{11}$$

$$= 18.9 \text{ horse power}$$

Now, the power in the ventilating current is 18.9 horse power, but 2.36 horse power is natural and is not due to the fan. The work done by the fan would therefore be 18.9—2.36 or 16.54 horse power.

TAKING ADVANTAGE OF A NATURAL CONDITION

Let us assume the fan to be reversed with the atmosphere outside the mine remaining at the same temperature. Then, to propel 60,000 cubic feet through the mine against the natural conditions would require 18.9+2.36 or 21.26 horse power. In this case the reversal of the air against the natural ventilation would require nearly fifty per cent more power than would be required if advantage were taken of the natural ventilation current. The reader can extend this investigation to any degree necessary to satisfy himself.

Sometimes a mine will have both inlet and outlet at the same altitude and yet the fan may work better blowing than exhausting, or vice versa. In which case the rubbing surfaces are more rugged and create more friction to the air when blowing than when exhausting, or vice versa. This can be determined by operating the fan to produce a given quantity blowing and then reversing the ventilating current so as to get the same quantity reversed. In observing the water gage when blowing and when exhausting, it will be observed that the water gage is rarely the same in the former case as it is in the latter. Which ever records the highest water gage for the same quantity of air is the most difficult condition, whether it is blowing or exhausting.

At the present time fans are usually driven by electric motors at a fixed speed. The fan thus produces a certain quantity of air while blowing. When it is reversed, running at the same speed, it will frequently produce more or less exhausting than when blowing, but rarely the same quantity one way as the other.

When fans were driven by steam engines, the speed could be varied to suit the conditions, and as a constant quantity of air was desirable, the fan was speeded up or down when the ventilating current was reversed, just as the occasion was required, so that the constant quantity might be maintained whether blowing or exhausting.

ADVANTAGES IN HAVING A REVERSIBLE FAN

A reversible fan is a very valuable installation in case of a fire within the mine. Mines frequently take fire from various causes which are generally unknown. The existence of a mine fire is the most distressing and dangerous thing possible for the mine management to encounter. The reversible fan enables the miners who are expert in handling the fire, to carry fresh air to the workmen at the point where it is most desirable to fight the fire. It also enables the management to take away the smoke and noxious gases so they will not interfere with those who are fighting the fire.

A reversible fan is valuable in a cold climate where ice is formed in the airways. By reversing the fan, the warm air from the mine can be passed over the ice that has formed from water in the intakes frozen by the outside air. The warm mine air will melt the ice and restore the airways to full capacity. Sometimes in gaseous mines the air current must be so directed that the return current does not pass along the haulage ways. If there is sufficient methane present to make an explosive mixture, the return current is dangerous on the haulage way, particularly when electric motors are used for hauling or when naked lights are used. In such mines a reversible fan is necessary.

In many mine fires and after mine explosions, a reversible fan could have been the means of saving many lives and much valuable property. It is not always necessary nor even desirable to reverse the air current after an explosion or in fighting a mine fire. The conditions within the mine after examinations by competent mining men will determine whether the air current should be reversed or not. This is a matter of good judgement on the part of those who make the examination and it is often a problem about which they are in doubt. But, if the fan is reversible, and it is advisable to reverse the air current, the means is at hand to do it quickly. Time is valuable in such a case and such a fan installation cannot be made quickly. The reversible fan should be installed in all mines working extensive areas of coal.

THE CURRENT SHOULD BE EXHAUSTING OR BLOWING; WHICH

There has been much controversy about the advisability of using reversible fans exhaust or blowing. They should be used either way, depending on that which best suits the conditions of the mine. Some mines can be worked best by exhausting the air and some by blowing. In either case, however, the fresh air should be gotten to the miners at the working faces as quickly as possible without passing it through old workings and vitiating it with noxious gases before it gets to the miners.

Many mining men contend that all gaseous mines should be worked with the fan exhausting. They allege that with an exhausting fan the air within the mine is below atmospheric pressure, and in case the fan should stop the outside atmosphere would restore its pressure to the mine and hold back the dangerous gases, whereas, if the fan were blowing and it stopped, the atmosphere would suck the dangerous gases into the mine workings. Let us examine this theory and see what truth there may be in it. It is a rare thing that a mine is operated on greater than 3 inches of water gage at the fan; which pressure at the working faces would not exceed one half of 3 inches, or 1.5 inches of water gage. Now, 1.5 inches of water gage represents 7.8 pounds pressure to the square foot. Whereas, the atmospheric pressure is 14.7 pounds to the square inch or 2,116.8 pounds to the square foot. The ratio of expansion of the gases due to the stoppage of the fan would therefore be as 1:271, which would not make any appreciable difference in the mine. The expansion or contraction of the gases to such a ratio as 1 to 271 is not sufficient to cause alarm.

ADVANTAGES OF A TWO SPEED MOTOR DRIVEN FAN

The conditions of a great many bituminous mines are such that they require a large volume of air at the working faces while the miners are at work. At night, on holidays and Sundays, a smaller volume of air is sufficient. Through experience it has been determined that one half the volume required when the mine is working full capacity is sufficient for holidays and Sundays. A two speed motor has been devised to meet this requirement. This motor consists of two sets of windings, one for full speed and one for half speed. The electric current is shunted from one set of windings to the other set through a switch known as a pole changing device. By the use of this motor and its pole changing switch, the fan can be changed instantly from full speed to half speed and the volume of air changed from full volume to half volume at once. The effect of this device is such that about five-sixths of the power applied can be saved when the fan is running at half speed. It will be remembered that the power changes as the cube of the quantity of air. If the quantity for holidays and Sundays is but half the quantity required for the mine working at full capacity, then power for one half the quantity should be only one-eighth of the power for the full quantity. We can illustrate this by an example:

Assume a mine requiring 100,000 cubic feet of air per minute at a 4 inch water gage for its daily use. By the use of the two speed motor and its pole changing device, the fan is operated at one half speed for nights, holidays and Sundays. The quantity at half speed will be one half of 100,000 cubic feet or 50,000 cubic feet and the water gage will be one inch. The water gage changes as the square of the quantity. For the full load the power will be:

$$H.\ P. = \frac{100{,}000 \times 4 \times 5.2}{33{,}000} = 63.03$$

And for the half load the power will be:

$$H.\ P. = \frac{50{,}000 \times 1 \times 5.2}{33{,}000} = 7.88$$

Which is one-eighth of the power required for full load. The machinery, however is not so efficient on the half load as on the full load due to the friction of the moving parts and, moreover, the winding on the half speed motor is not so efficient as on the full speed, so that in practice, the saving in power by the use of the half speed motor is approximately five-sixths of the power required for the full load. As an illustration of this device, the record given below:

Commercial Coal Mining Company
Twin Rocks, Penna.

FAN MOTOR COLL'Y NO. 4

Westinghouse Electric & Mfg. Company
Motor, Type CL, Induction, constant speed H.P.'s. 75—37½.
Volts 2200, 3 Phase, 60 Cycles, 1140 and 570 Speed, Belted
to a Robinson 8 ft. Fan

High Speed

Cu. Ft. air per minute	84600
Water Gage	2.7″
Motor Speed	1175 R.P.M.
Fan Speed	288 R.P.M.

Voltage	2260
Amperes per Phase	10
K.W	42.0

Slow Speed

Cu. Ft. air per minute	37800
Water Gage	.7″
Motor Speed	596 R.P.M.
Fan Speed	150 R.P.M.
K. W.	6.8

It will be observed that the given power on the half load is nearly one-sixth of the power on the full load. The loss on the half speed being due to the friction and the winding of the small motor.

The mechanical efficiency is also low as will be observed from the problem:

$$M.\ E. = \frac{\dfrac{84{,}600 \times 2.7 \times 5.2}{33{,}000}}{56.3}$$

$$= 63.9 \text{ per cent}$$

63.9 is only a fair mechanical efficiency. In such cases the loss should be sought. Let us look at the equivalent orifice of the mine and see if we can find the difficulty. The equivalent orifice of this mine is found from the following:

$$E.\ O. = .0004 \times \frac{84600}{\sqrt{2.7}}$$

$$= 20.63 \text{ square feet}$$

The equivalent orifice is small with an area of only about 20 square feet. The fan is 8 feet in diameter. Its volumetric capacity is too large for such a mine with only 20 square feet of equivalent orifice. The mine should have its airways cleaned, or enlarged, or if that is not practical, the fan should be replaced with a smaller one.

Let us look into this form of installation further and see what the actual saving is by the saving in power. It is the saving in money that is the final test of the actual value of this two speed motor device. Assuming that two cents per hour is the value of a kilowatt of electrical energy, and that the mine operates 200 days of 10 hours each, in one year, at full capacity. Then, what is the actual saving through the use of this device in dollars and cents for one year? If the fan were running 365 days at full speed with a constant speed motor, the cost of operation would be as follows:

$$365 \times 24 \times 42 \times .02 = \$7{,}358.40$$

This is the maximum for one year. Now, the full speed of the fan will be required for 200 days with the two speed motor, and all other time will be on one-half speed. The cost for 200 days of 10 hours each would be as follows:

$$200 \times 10 \times 42 \times \$\ .02 = \$1{,}680.00$$

And, the cost for the remainder of the year would be:

$$(165 \times 24 \times 6.8 \times \$\ .02) + (200 \times 14 \times 6.8 \times \$\ .02) = \\ \$538.56 + \$380.80 = \$919.36$$

The total cost of operation with the two speed motor and pole changing device would be:

$$\$1{,}680.00 + \$919.36 = \$2{,}599.36$$

The saving money value would therefore be, the difference between

$$\$7{,}358.40 \text{ and } \$2{,}599.36 \text{ or } \$4{,}759.04$$

The saving by this device is very great and when the fan is belted or geared to the motor, almost any quantity of air desired can be obtained and the unit worked under the greatest efficiency.

VARIABLE SPEED MOTOR

The variable speed motor is sometimes used to give the fans speeds between half and full speed. It is operated by a controller which makes the motor efficiency vary about as the speed varies. The fan can be operated at any desired speed between half and full speed. If the mine can be operated with the fan at half speed during holidays and nights, this controller is not so economical of power as the two speed motor. We have seen how the two speed motor saves five-sixths of the power when the fan is reduced to half speed. Let us see what the variable speed motor does on half speed.

The efficiency of the variable speed motor may be assumed as 90 per cent at full speed, and at half speed, it will be 45 per cent. The load in the above example at full speed is 42 kilowatts. Both motors have the same efficiency at full load, so there would be no difference in the economy at full speed. At half speed the variable speed motor is only 45 per cent efficient and as the load is only one-eighth of 42 kilowatts or 5.25 kilowatts, the actual power consumed by the variable speed motor would be a number of which 5.25 is 45 per cent or 11.7 kilowatts.

The two speed motor consumed 6.8 kilowatts, so the difference between 11.7 and 6.8 kilowatts or 4.9 kilowatts is the power saved by the two speed motor in the example above. At two cents per kilowatt hour, the saving would be approximately ten cents per hour for each hour on which the fan was running at half speed.

In the above example, we found the fan on half speed cost $919.36 for the year. With the variable speed motor running the fan at half speed during the same period, we find the cost to be as follows:

(165 × 24 × 11.7 × $ .02) + (200 × 14 × 11.7 × $ .02)
=$1,682.84

The difference between the two amounts is $763.48 which is the saving in favor of the two speed motor, in the example above.

The variable speed motor would, of course, give any speed between half and full speed and in many cases that advantage might justify a small loss.

Questions on Chapter XI

What must you know of a mine in order to specify a fan for your mine?

What knowledge of the fan must you obtain before making specifications?

What three natural laws govern the flow of air?

How does the fan speed assist in specifying the fan?

State formula for determining the peripheral speed of a fan.

How do we determine the intake orifice of a fan?

How is the width of a fan determined, when diameter and volumetric capacity are known?

What should be the size of the outlet or discharge orifice?

Is it possible to have a fan too large installed at a mine?

Name some of the disadvantages in having a fan too large.

Should the speed of the air through the intake orifice be limited?

Is it practical to replace a fan, and for what reason?

Will improved mine conditions affect adversely the efficiency of a fan, and why?

What is a reversible fan?

Why are some mines more easily ventilated by exhaust than blowing current and vice versa?

Note conditions at your mine and explain why this is or is not true.

Name some of the advantages obtained with a reversible fan.

What advantages are had from a two speed motor driven fan?

How much power may be saved by reducing the quantity of air to one-half on Sundays and holidays?

What is a variable speed motor, and for what purpose is it used?

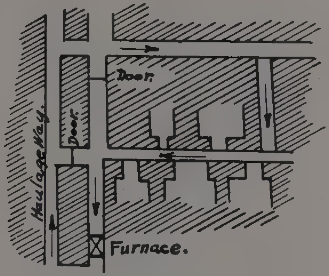
CHAPTER XII

SPLITTING THE CURRENT DECREASES COSTS

The early methods of mining were crude as we understand them now. There was no plotting of a mine on paper or even in the heads of the management. The miner just dug coal where he could best find it in the easiest way. There was no system of haulage or drainage or ventilation. The work was carried on mostly by chance. By long years of experience, the miner learned to do his mining in such a manner as to drain the water from the mine and to take care of the haulage ways. These drains and haulage ways were used for the air current to find its way into and out of the mine. As the mining art developed, it was found necessary to provide airways that were not used for drains or haulage ways, and eventually a system of mining was developed which took care of the air current as a primary thing and not as a side issue. Of late years the miner has learned that the ventilation of the mine should be given the first thought in the layout of the mine. He has learned that the ventilation is the most important factor in his work. He has learned that the ventilation takes most power of any operation about his mine, and in many cases, more power than all other operations combined. He is therefore, laying out his new mines with a view to conserve his power through a proper layout of his airways when planning his mine and the proper care of the airways after they are made.

NO THOUGHT GIVEN TO VENTILATION BY FIRST OPERATORS AND MINERS

The earliest mine with which the author is familiar is one in the Pittsburgh seam of coal near Brownsville, Pennsylvania. This mine was in operation more than one hundred years ago. It has partly fallen in but there is enough of the old workings standing to give the observer a good idea of how the work was carried on. There was no system of room and pillar, projected haulage, or ventilation entries. The coal was mined in galleries which were nearly circular when finished. The miners, no doubt, worked the faces in this manner until the roof came in on them and then they moved on to some other place. The coal was hauled out in carts. There were no tracks or flanged wheel wagons. The air evidently circulated as best it could from the atmospheric pressure outside, through the workings, as the seam was more than 8 feet thick and the galleries were large. The miners, no doubt, had sufficient air. It was a drift mine and the workings were not far under ground.

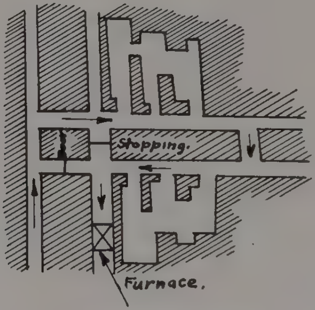


Single Entry System

The first effort at a system of ventilation seems to have been in the single entry system, as shown above:

This system required numerous doors which caused leakage when they were closed properly and were extremely dangerous when left open. They required attendants also, which was expensive.

This system developed into a double entry system as shown below:

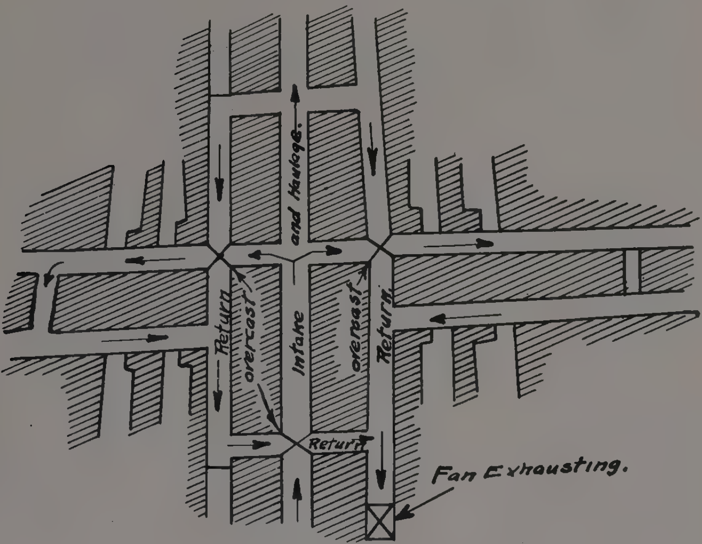


Double Entry System

This was an improvement over the single entry system but it still required doors with the consequent leakage and cost of attendance. A great many mines are operated on this system at the present time, and are carrying their ventilating air in one current with no splits through the entire mine. The water gage is high in such mines and the equivalent orifice is always small.

The three and four way system of intake and return is more generally used in mines recently opened. The three way system is illustrated on the opposite page.

The illustration with its arrows shows the fan exhausting. If the fan is a reversible one, then the manipulation of the doors and chambers surrounding it, will reverse the ventilat-



Triple Entry System

ing current without difficulty, as the overcasts take care of the reversed currents. If the mine were equipped with trap door instead of overcasts, the doors would have to be changed on their frames to suit the reversed current, that is, with the old style doors. The automatic doors will work when the current is reversed without changing their setting. The three entry system uses one entry for intake and haulage way and two entries for return. This is the custom but sometimes when the fan is reversed, the haulage way is the return. In gaseous mines the use of the haulage way for return air currents is dangerous if the inflammable gases are not sufficiently diluted to render them harmless. In cold climates the return air current is used to melt ice from the haulage way. This is a very desirable thing but there must be sufficient volume of air passing through the mine to render the air perfectly safe from explosions.

FOUR ENTRY SYSTEM AND ITS ADVANTAGES

The four entry system resembles the three entry system but possesses two intakes and two returns. This system was developed on account of the haulage, rather than because of the ventilation, for it gives an ingoing track and an outgoing track which greatly facilitates haulage. Just as a two track railway system facilitates the transportation in comparison with a single track system.

It will be noted in the illustration, page 135, that each side of the mine has its own separate air current. The main air current enters the haulage way and divides at some convenient place, one current going to one side of the mine and one to the other side. Where the main current divides into two branches is a split, as it is termed by the miner. This splitting of the current has great advantages which will appear on investigation.

DISADVANTAGES OF A HIGH VELOCITY CURRENT

The ordinary bituminous mine has one intake which is the haulage way. This intake usually has no more than 60 square feet of sectional area when it is clear of wagons. Such a mine usually requires 100,000 cubic feet of air per minute or more. The center velocity required in a 60 foot airway to produce a 100,000 cubic foot will be approximately 2,000 cubic feet as the rough sides of the airways reduce the velocity at the sides, roof and floor of the mine. The velocity is too high to carry lights or, for men to work in, for even if the air is warm they cannot work in such a velocity.

MOST SATISFACTORY VELOCITY FOR VENTILATING CURRENT

When the current is divided at the split, then the velocity is reduced to 1,000 feet per minute provided the splits are each the same area and present the same resistance to the air current. This system of splitting can be carried on indefinitely until the various working places have the fresh air needed, but the velocity of any split should not be less than 200 feet per minute. A less speed does not properly brush out the workings.

SPLITTING THE AIR DECREASES THE RESISTANCE

Now, assuming that the main air current which is all in one current at 2,000 feet velocity per minute is split into two currents of 1,000 feet velocity per minute each. What effect will the new arrangement have on the resistance? The resistance as measured by the water gage varies as the square of the velocity. The square of the velocity of the main current is to the square of the velocity of each split as four is to one. But, as there are two splits the resistance of the two air currents is just one half what it would be if they were merged into one current. In other words, we have two splits of 50,000 cubic feet per minute at $\frac{x}{4}$ inches of water gage instead of one air current of 100,000 cubic feet per minute at x inches of water gage. The total of the two splits would therefore be 100,000 cubic feet per minute at $\frac{x}{2}$ inches of water gage.

SPLITTING THE AIR REDUCES THE POWER REQUIREMENTS

The power required to drive the ventilating current varies as the cube of the velocity. The power required to drive each of the splits in the above example would therefore be one-eighth of the power required to drive the main air current. But, as there are two of these currents, the power required to drive both of them would be one-fourth of the power required to drive the main air current.

Questions on Chapter XII

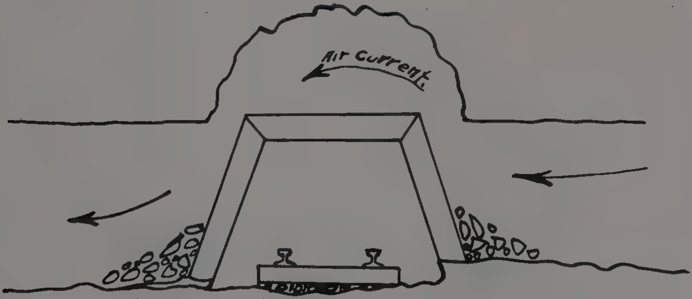
What should be given first consideration in the projection for a mine?
Why was the single entry system of mining a failure?
Why could the double entry not solve the problem of ventilation?
Name some of the advantages of a multiple entry system.
What are some of the disadvantages of a high velocity current?
What speed should be the minimum velocity, and why?

CHAPTER XIII

REGULATORS AND OVERCASTS, THEIR EXCAVATION AND CONSTRUCTION

It will also be noted that when the air divides into two splits it must cross the return current from the intake to the side entries. To accomplish this without mingling the two air currents an overcast is made to cross over the airway containing the return current. This overcast is made by shooting out the roof of the airway containing the return current and building a sort of bridge structure the size of the return airway so as to make the latter continuous and permit the intake air to pass over the return current without mingling with it.

These overcasts are usually made with very little care and are so constructed as to offer to the air current passing through them, the greatest possible resistance. The usual method is shown in the illustration below, and is a faithful picture of many overcasts that the author has examined. This is the way not to do it:



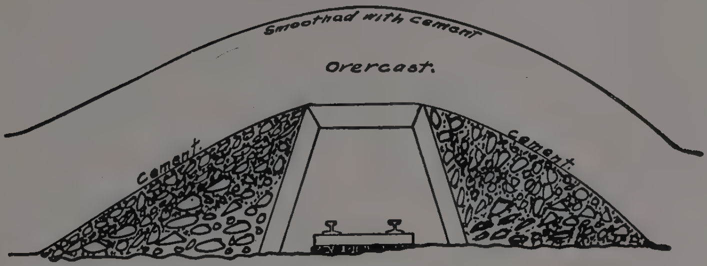
Overcast—bad construction

The roof is shot down just a few feet wider than the airway which the overcast is crossing, and the rock is removed from the mine. The bridge structure is then built making the airway continuous, but the overcast is left in the most ragged shape possible and the space between the roof and the sides of the bridge structure is hardly sufficient to enable a man to pass over and through the overcast. This construction makes resistance that can scarcely be calculated.

RESULT OF CARELESS OVERCAST CONSTRUCTION

The author once was called upon to investigate a mine which was badly in need of air on one of the cross headings and following the course of the air, he found that the overcast leading from the main current to the split was in the condition shown in the above illustration. On one side of the overcast between the bridge over the haulage way and the edge of the roof was an average of 18 inches wide and 8 feet long, giving an area of 12 square feet. 20,000 cubic feet of air was desired on this split. To pass 20,000 cubic feet of air per minute through this narrow space required a mean velocity of over 2,000 feet per minute, which represents a pressure of more than a quarter inch of water gage for this place alone. It was with the greatest difficulty that the mine management was persuaded that this overcast should be put into proper condition to pass the air through it. On the opposite page is the illustration showing the way to do it.

The rock shot down from the roof in the illustration should be used to fill from the bridge structure in the haulage way into the airway and long curves should be made in the roof and on the floor of the mine so as to make the overcast have

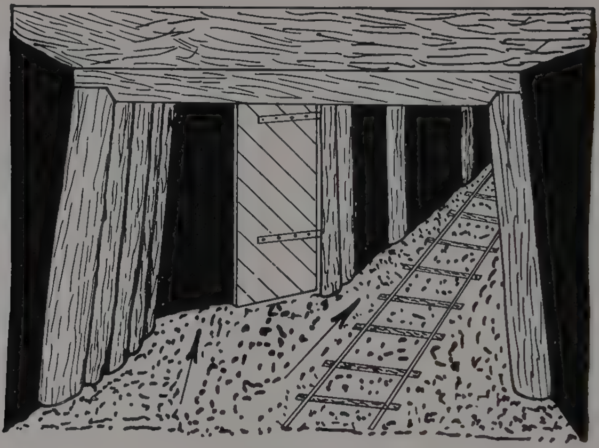


Overcast—correct construction

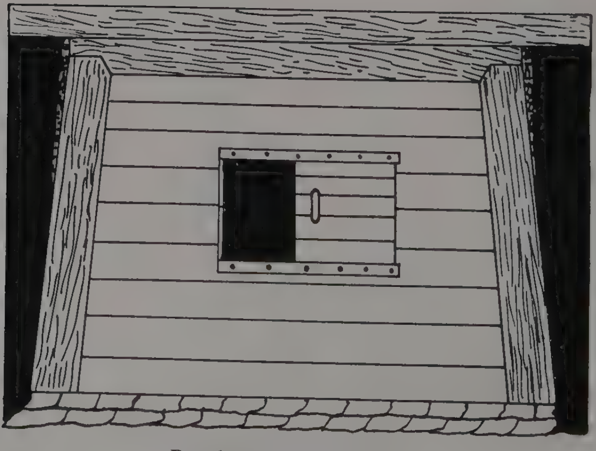
the same sectional area as the airway itself. The curved surfaces should be gone over with a cement gun and smoothed up so they will present the smoothest surface possible to the air current. There should be no huge hole shot out into the roof. The roof should be removed above the bridge structure only the height of the airway on either side. A large hole in the roof makes a pocket for the air to eddy around and rotate on itself. This action requires power to keep it in motion and the air which is eddying and rotating is not moving forward to effect its function of ventilating the mine. All such places in a mine retard the air current. They furnish obstructions to the free passage of the air. In the case of an overcast they can easily be properly made. There are places where the roof falls and must be removed. These places are unavoidable and it is not practical to fix them properly. There are enough of such places in the ordinary mine without deliberately making them in the overcasts.

SPLITS OF UNEQUAL RESISTANCE

Sometimes these splits are not of equal area nor of equal length and the air current is offered greater resistance in one



Regulator Door



Regulator Door in Brattice

than in the others. The result of this condition is that the splits which have the greatest resistance get the least air and those with the least resistance get the most air. The air current naturally seeks the path of the least resistance. In general, the split which gets the least air is the one which needs the most, for the long splits usually work the most men and therefore, need the most air. But, owing to the length of the split, the resistance is greater than the resistance for the shorter splits and therefore, the short splits get more air than they need and the long ones get less than they need.

THE REGULATOR, ITS VALUE TO A VENTILATING CURRENT

This condition is very common and is usually remedied by regulators. The regulator is placed in the split with the least resistance and enough air allowed to pass through it to ventilate the split properly and the surplus air which would pass through the split if there were no regulator is forced to pass through the other airways. This regulator is usually a door in the airway partially left open, just enough to pass the required amount of air. Sometimes it is a brattice across the airway with a small door in the brattice which can be opened or closed to suit the flow of the air through the split. The illustrations show the idea of each.

As many of these regulators can be applied as the mine requires. They can be closed until the back pressure caused by them makes sufficient pressure to pass the required amount of air through the split with the greatest resistance. Provided, now bear this provided in mind, the fan can make sufficient pressure to overcome the artificial resistance caused by the regulators, and then, force the air through the difficult split.

EFFECT OF REGULATOR ON MINE RESISTANCE

Each and every regulator, of whatever nature, puts artificial pressure on the fan. They cause more resistance to the air and decrease the equivalent orifice of the mine, in proportion to the increased resistance.

Nearly all mines are difficult to ventilate because of the smallness of the equivalent orifice, and this regulator method of conducting the air adds more resistance and decreases the equivalent orifice, when an enlargement of the latter is the thing needed. It is obviously not the thing to do when electric current is in nearly every mine. The equivalent orifice being small should be enlarged and not constricted.

It is obvious that if the split which requires more air, cannot be enlarged or cleaned to take the required amount of air, the remedy is not to place more pressure on all the mine to accommodate the one split, but to decrease the pressure in that portion of the mine which has too great a resistance. This can be done by overcoming the resistance in the portion of the mine where it is excessive by an auxiliary fan.

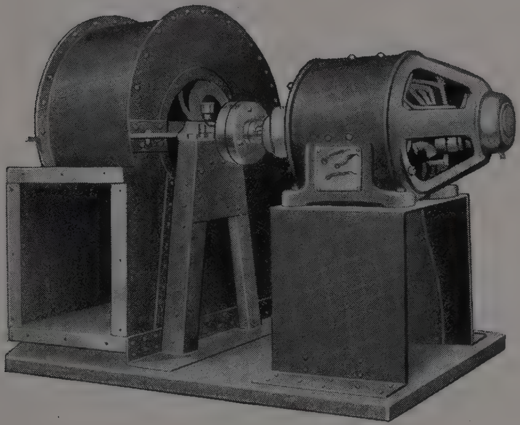
Questions on Chapter XIII

Of what use is the overcast in a mine?
What kinds of overcasts do not give satisfactory results?
Make sketch showing an overcast for an efficient split of air.
Why should a smooth surface be provided for the air current?
What causes unequal resistance in different splits?
What is commonly done to equalize the resistance in splits?
Describe two common classes of regulators.
What effect has a regulator on the mine resistance?
What may be used to overcome resistance in a primary split?

CHAPTER XIV

AUXILIARY OR "BOOSTER" FANS, THEIR USES AND EFFECTS

The auxiliary fan is not generally understood as it should be. The general opinion of this device is that it simply churns the air around, and does not much affect the ventilation. This view is correct of most auxiliary fans. They are usually disc fans which are unable to overcome the resistance they encounter, and consequently they do churn the air back and forth through themselves. That is not the fault of the fan, as an auxiliary, but of those who install it in not understanding the requirements of the portion of the mine in which the auxiliary fan is placed. All fans must have the capacity to create pressures which will overcome



Direct-connected Auxiliary Fan

the resistances they encounter, whether they are auxiliary or primary.

The auxiliary fan must therefore be studied and also the portion of the mine which it is to ventilate should be studied so that the fan may meet the requirements of the mine.

AN EXAMPLE OF CREATING ARTIFICIAL RESISTANCE WITH REGULATORS

We have seen that the main airways may conduct the air through the portion of the mine they traverse without undue resistance. The side headings and certain splits are making so much resistance that regulators are used to force the air through the splits with the greatest resistance. These regulators act as dams to the air, impeding its flow through the mine and making a back pressure on the fan. We may illustrate this with an example which will make it more obvious.

Suppose a mine where the ventilation is 200,000 cubic feet of air per minute at 2 inches water gage, and the air is flowing freely through the mine, unobstructed by regulators? There is a long and tortuous split at the back of the mine which is not getting sufficient air, without the use of regulators on the other splits. This long split must have more air and by the use of regulators on the other splits, the necessary air is forced to pass through the long split. This method of damming back the air increases the water gage, let us assume, from 2 inches to 3 inches. Now, what is the result on the power? The first case shows the power in the air:

$$H.\,P. = \frac{200{,}000 \times 2 \times 5.2}{33{,}000} = 63$$

The second case shows the power in the air as:

$$H. P. = \frac{200,000 \times 3 \times 5.2}{33,000} = 95$$

This result shows a difference of 32 H. P. due to regulators. Thirty-two horse power in the air is nearly 24 kilowatts. If the loss is due to inefficiency of the machinery is taken into account, then, the power loss would be about 34 kilowatts. The money loss, charging the power at two cents per kilowatt would therefore be per year:

$$365 \times 24 \times 34 \times \$\ .02 = \$5956.80$$

ADVANTAGES GAINED BY USING AUXILIARY FAN

This loss is directly due to the regulators. If an auxiliary fan were placed in the long split, the power required to operate it would, of course, have to be accounted for. Suppose the long split should require 30,000 cubic feet at ½ inch water gage. This amount at the back part of the mine would require the additional pressure on the part of the fan that we have just accounted for. The 30,000 cubic feet of air per minute at ½ inch water gage would require about five horse power in the air and about 7 kilowatts of electric power to propel it through the long split, allowing the machinery to have about 50 per cent of efficiency on this low duty. The cost of this power at two cents per kilowatt hour per year would be:

$$365 \times 23 \times 7 \times .02 = \$1226.40$$

The saving by the use of the auxiliary fan would in this case be $5956.80 less $1226.40 or $4730.40. From this would have to be deducted the cost of the auxiliary fan and its motor which would probably be about $1000.00

leaving a net gain of $3730.00 to the advantage of the auxiliary fan, when considered for only one year. This may seem like an extreme case but, it is not. It is fairly typical of the saving that can be made by the use of an auxiliary fan on a mine using 200,000 cubic feet of air per minute under the above stated conditions.

The reader can apply the above to any mine with which he is familiar and will, no doubt, see where a great saving can be obtained by removing regulators and installing auxiliary fans.

STOPPINGS A GREAT FACTOR IN MINE VENTILATION

The air that gets to the working faces is only the air that effectually ventilates the mine. The quantity at the working faces is often but a small fraction of the air delivered to the mine by the fan. Good practice requires that the stoppings in a mine should be tight enough to pass not less than 80 per cent of the air delivered by the fan to the working faces. There are many mines, however, that deliver not more than 40 per cent of the air delivered by the fan, to the working faces. Such mines are very wasteful of power. Suppose the above mine with 200,000 cubic feet of air per minute is passing but 40 per cent to the working faces, the loss being due to bad stoppings.

Now, suppose that the stoppings were so improved that 80 per cent of the air leaving the fan could be passed to the working faces. It is obvious that 100,000 cubic feet per minute leaving the fan would pass the same quantity to the working faces, after the stoppings were improved as 200,000 cubic feet did before. The mine would, with the improved stoppings need a fan to make 100,000 cubic feet per minute instead of a fan to make 200,000 cubic feet per minute. Making the stoppings tight so as to get the same quantity of air at the working faces would, no doubt, require the same pressure at the working faces. But, as the speed of the air in the main headings would be reduced to half its original speed, the pressure of the fan therefore, would not likely be increased. In each case, the working faces would be supplied with 80,000 cubic feet of air per minute.

EFFICIENT STOPPINGS ARE A PROFITABLE INVESTMENT

Now, suppose the mine when passing 200,000 cubic feet required a 3 inch water gage, the power required in the air would be 93 horse power and if the same pressure were required to pass 100,000 cubic feet per minute, the power required would be but 46.5 horse power. In other words, by the improved stoppings a saving of 46.5 horse power would be effected while the miners received 80,000 cubic feet of air per minute at the working faces in each case. Assuming the fan and motor in each case to be 70 per cent efficient the horse power saved would be 66.4 or 49.5 kilowatts. The power saved for one year at two cents per kilowatt would be:

$$365 \times 24 \times 49.5 \times \$\ .02 = \$8672.40$$

EXCESSIVE QUANTITY OF AIR ABSORBS HUMIDITY

The changed condition of the mine which came about through the improvement in the stoppings, where the quantity of air leaving the fan was but one half its former quantity would necessitate a fan to meet the new requirements of the mine. This new installation would be justified if only the question of power were concerned. There is another question which is also a very important one. The passing of large quantities of air through a mine that is dusty, is to be avoided as much as possible. Each cubic foot of air passing through the mine absorbs a certain amount of moisture from the dust. If the quantity of air passing is in excess of what is needed the moisture carried away will have to be replaced by some expensive means of moistening the air or a dangerous conditions of the mine is created.

Passing 100,000 cubic feet of air may not necessitate the use of any moistening devices, but on the same mine passing 200,000 cubic feet of air per minute may make such devices imperative. There is another advantage in the less amount of air leaving the fan. In many mines the roof is very difficult to hold where large quantities of air pass through the main airways. These mines should have sufficient air passed through them to supply the miners at the working faces, but no more. From the foregoing discussion, it will be seen that long splits will be best served by an auxiliary fan. Now, how shall we determine what the requirements of the split are? And, how shall the fan be applied so that it will give the most efficient service?

DECIDING ON THE PROPER AUXILIARY FAN FOR A SPLIT

We can best discuss this by use of an example. Let us assume a split that is 2,500 feet long from the main airway. This split will then have a length of travel for the air of 5,000 feet. Assume the airway is 6 feet high and 8 feet wide and that it is desired to pass 30,000 cubic feet of air per minute through the last cut through. What will the pressure be in this split? What power will be required to pass the given quantity?

In a long split which is difficult to ventilate, it is customary to use Fairley's coefficient so as to be on the safe side. Transposing in the formula:

$$i = \frac{ksv^2}{a \times 5.2} \qquad \text{we have}$$

$$i = \frac{.00000001 \times 140{,}000 \times 360625}{48 \times 5.2}$$

$$= 2.2 \text{ inches}$$

The water gage for a long split is usually too high for a disc fan consequently we must consider only a centrifugal fan for such a purpose. The usual complaint against auxiliary fans comes from the use of disc fans where the water gage is too high for them to overcome the resistance. The power required to drive 30,000 cubic feet of air per minute at 2.2 inches water gage is:

$$H.\,P. = \frac{30{,}000 \times 2.2 \times 5.2}{\dfrac{33{,}000}{.70}} = 14.85 \text{ horse power}$$

A 15 horse power motor would be proper to use on this split with a centrifugal fan.

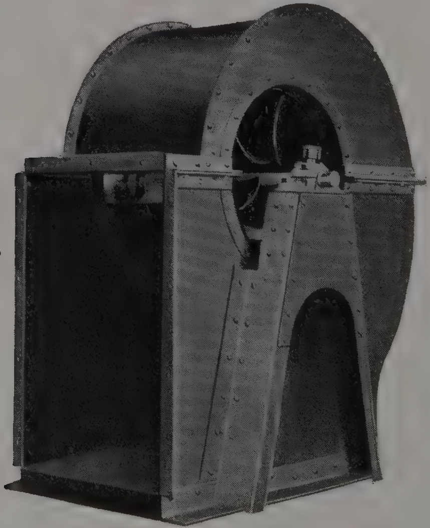
DECIDING ON THE SIZE OF AN AUXILIARY FAN

The next thing to determine is the size of the fan to use. The water gage is 2.2 inches which corresponds in speed to about 5,800 feet. The periphery speed of the fan should be 20 per cent less than this speed, considering the fan with advancing curved blades. The periphery speed necessary to overcome the resistance is therefore, 4,640 feet.

The orifice of passage of the fan should be such that a speed of 5,800 feet per minute will pass without the necessity of additional speed in the air. Allowing the *vena contracta* of .62 the orifice would be:

$$\frac{30{,}000}{5{,}800 \times .62} = 8.3 \text{ square feet}$$

If the fan were a double inlet, three feet in diameter would be sufficient orifice of passage. Three feet being determined, as the diameter of the wheel, what speed should the wheel rotate? A three foot wheel has a periphery of 7.07 feet and as its speed must be 4,640 feet, the number of revolutions would be 4640 ÷ 7.07 or 656 R.P.M.



Auxiliary Fan without Drive

The width of the wheel can be determined by the volumetric capacity. Suppose the wheel has a volumetric capacity of 250 per cent. The width of the wheel would then be:

$$\text{Width of Wheel} = \frac{30{,}000}{3 \times 3.1416 \times 656 \times 2.5} = 1.9 \text{ feet}$$

The outlet of the fan must be of sufficient size to equal the orifice of passage which is 8.3 square feet. From the foregoing example of a long split it is evident that a centrifugal fan with advancing curved blades, three feet in diameter and two feet wide, running at a speed of 656 R.P.M., will meet the necessary requirements of the split. The example taken is not an extreme case, but a very ordinary one. It shows how the pressure must be put on the primary fan if an auxiliary fan is not used.

AUXILIARY FANS SERVE TO LENGTHEN LIFE OF PRIMARY FANS

The example shows a 2.2 inch water gage for this split. If the regulators be used on the other splits of the mine so as to force 30,000 cubic feet per minute through this split, the water gage of 2.2 inches will be passed back to the primary fan. In general, such practice makes the primary fan inefficient, not only in volumetric capacity but in mechanical efficiency. The most noticeable feature of the action of the primary fan when this damming back process of the regulators is in use, is the backing out of the air from the fan wheel at or near the cut off. This backing out of the air from the fan wheel is always caused by the back pressure from the mine. The equivalent orifice of the mine is always too small for the orifice of passage of the fan, in such cases.

Where such mine conditions exist and the pressure is thrown back on the fan, the efficiency of the fan is not only impaired, but the fan wheel is likely to be destroyed by whipping of the air at the cut off. Most of our modern steel fan wheels that have been condemned because they require to be riveted frequently, have been destroyed because of this damming back process of regulators. The construction of the wheel may have been all that could have been desired in the work they were intended for but the churning and whipping of the air at the cut off due to the excessive pressure of the mine causes the air to be taken into the wheel and a large portion thrown out again. This action chokes the blades as they reach the cut off and causes a reaction on the blade after it passes the cut off which strains the rivets and the various braces of the wheel.

Questions on Chapter XIV

What erroneous belief do most people have concerning auxiliary, or "booster" fan?

Why are auxiliary fans frequently not successful installations?

Give the difference in monetary cost between the use of a regulator to increase resistance and a fan to decrease resistance.

What is the effective ventilation of a mine?

What loss of power is being experienced in your mine by reason of defective stoppings?

Why is an excessive volume of air to be avoided?

What factors must you know for the purpose of specifying an auxiliary, or "booster" fan?

How can you precisely specify the type, size and speed of an auxiliary fan?

What effect has the installation of an auxiliary fan on the life of the primary fan?

CHAPTER XV

SPECIFYING A FAN FOR ACTUAL REQUIREMENTS

The fan as a machine for creating pressure on a mine, is subjected to many conditions which make it efficient or inefficient. These conditions often make a fan that is an excellent machine seem inefficient. Nearly all fans are efficient if the conditions of the mine suit the characteristics of the fan, and the reverse of this is also true. All fans are inefficient if the conditions of the mine do not suit the characteristics of the fan.

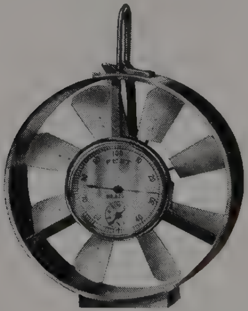
Each and every mine should have a fan made to suit the mine. The conditions of the mine should be observed and studied and a fan whose characteristics suit the characteristics of the mine should be installed. The power applied to the fan drive is of such importance that, from a point of economy, it is essential that the fan suit the condition of the mine.

After installation all fans should be frequently tested and watched in order to see that they perform in an economical manner. If the mine cannot be kept in a condition that makes the fan an economical unit, then the fan should be changed to suit the new conditions, provided the changed conditions are of a permanent nature.

This leads us to a study of fan tests. How is it done? A mine fan is usually tested first as to the air and second as to the power applied. The first test is to determine the number of cubic feet of air per minute that is flowing through the mine and at what pressure or water gage. The second is to determine the horse power applied to drive the fan, whether a steam engine, motor or other form of power. The comparison between the flow of air and the consumption of power is the basis of all calculations as to the economy of action.

MEASURING THE QUANTITY ACCURATELY

To obtain the amount of air current, it is usual to apply the instrument known as the anemometer. This is a small disc fan mounted in a frame and geared to a dial, the hands of which register the speed of the air. This anemometer is held in the airway, usually in the center of the airway, and the velocity of the air is read from the dial. The time is usually one minute for one reading. The area in square feet is computed for the airway at the exact place where the reading was obtained and the product of the speed and the area gives the volume of air passing the point where the velocity was read. As the time usually taken is one minute,


Anemometer

the reaidng shows the cubic feet of air per minute passing the point where the reading was taken.

It is customary to take the anemometer reading in the center of the airway. That gives the greatest velocity and not the mean velocity. The latter is usually obtained by holding the anemometer at four or five different places in the airway and averaging the velocity obtained in each place. Sometimes when a very large fan is being tested when the power applied is unusually high, the airway is sectioned off with wires into a number of spaces and the anemometer is held in each section for a given time. The number of sections multiplied by the time the instrument is held in each section, equalling one minute or any number of minutes that is decided upon. The mean speed for one minute is thus obtained.

For example, an airway is 6 feet high 9 feet wide making an area of 54 feet. Six wires are stretched vertically and six horizontally, so as to divide the airway into 36 spaces. The anemometer is held five seconds in each space. At the end of three minutes, the anemometer has been held five seconds in each of the 36 spaces. The reading on the dial is divided in three which gives the mean speed for one minute. This method reduces the speed of the air as read by the anemometer much below the center velocity as taken by one reading in the center of the airway. The average is more accurate than one reading in the center of the airway, but as it is not customary, it should not be used in comparison with tests taken under the usual methods.

At the same time as the air is read, the power should also be read; for any fluctuations in the pressure of the steam, if a steam engine is being tested, will change the results nearly as the cube of the fluctuation. Likewise, if an electric motor is used, the voltage and amperes must be carefully read at the exact time as the air is read, as the fluctuations in the voltage will change the results nearly as the cube of the fluctuations.

With an electric motor test, it is much more accurate to use a watt meter over a period, say, for instance, of one hour, and read the air in the mine at intervals of ten minutes during the period the watt meter is read.

ACTUAL TESTS AT DIFFERENT MINES OF DIFFERENT FANS

The power applied to the air in the ventilating current divided by the power applied to the motor is termed the mechanical efficiency of the unit. If the motor or engine is belted, the belt loss must be accounted for. The same applies to other form of gearing. That the reader may get an idea of the various types of fans and the mechanical efficiency of each under fairly favorable conditions, where the characteristics of the fan are suitable to the conditions of the mine, the following tests are given:

The first of these is of a Guibal fan direct connected to a steam engine. The engine was indicated at the same time that the velocity was taken in the airway. The varying volumes were due to the air being read while a regulator was being adjusted in the airway. It will also be noted that the fluctuations of the steam pressure changed the speed of the engine somewhat.

Pennsylvania Coal & Coke Company's Air Test

October 6, 1911, Ehrenfeld Shaft No. 4

16′ × 6′ — Guibal Fan Connected to 14⅜″ × 18″ Engine

Time P.M.	R.P.M.	Area	Velocity	Volume	W.G.	H.P. in Air	H.P. Ind.	Mech. Eff.
12:35	116	40	1800	72,000	3″	34.1	66	51.6
12:45	115	40	1650	66,000	2.95″	30.6	61.4	49.8
12:55	112	40	1675	67,000	2.9″	30.6	57.8	52.9
1:15	113	55	1100	70,225	2.9″	32.1	57.88	53.7
1:25	116	61.5	1000	61,500	3″	28.1	60.3	46.6

The first thing observed by the reader will likely be the mechanical efficiency. It is not too high nor is it too low. This is just about such a medium performance as is very common. What is the difficulty? Why should this fan not produce better results? Let us first examine the mine for the equivalent orifice. Let us take the last run when the air is passing through the mine with the area of the airway at the full. We have then for the equivalent orifice:

$$E.\,O. = .0004 \times \frac{61{,}500}{\sqrt{3}} = 14.22 \text{ square feet}$$

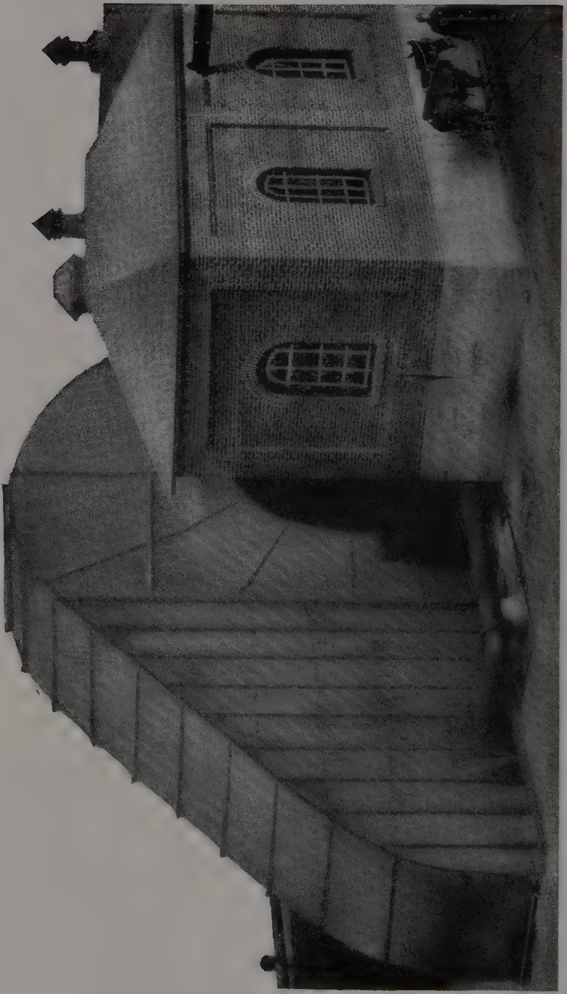
The equivalent orifice is exceedingly small. The airways are evidently in bad condition.

The manometric efficiency of the fan is good:

$$W.\,G. = \frac{\frac{(16 \times 3.1416 \times 116^2)}{60}}{32.16} \times \frac{1.2}{1{,}000} \times 12 = 4.19 \text{ inches}$$

The theoretical water gage is 4.19 inches and the actual water gage is 3 inches. The manometric efficiency is therefore, 71 per cent. The volumetric capacity is also very low:

$$C = \frac{61{,}500}{\left(\frac{16}{2}\right)^2 \times 3.1416 \times 6 \times 116} = 44 \text{ per cent}$$



Robinson Fan—Ronco Mine

This fan should have a mechanical efficiency of approximately seventy per cent. It has but 46.6 per cent under its daily load. Its manometric efficiency is good although it is working against adverse conditions. It should have a volumetric capacity of about 80 per cent and it has but 44 per cent. All these losses which seem to be in the fan are due to the small equivalent orifice of the mine. This fan would work with fair efficiency if the airways were enlarged or cleaned, or the air split into more currents. This test was taken by the engineers of the Pennsylvania Coal & Coke Company.

The second of these tests is of the 25 foot fan at the Ronco Mine of the H. C. Frick Coke Company. The record is as follows:

Ronco Mine H. C. Frick Coke Co.

December 17, 1905

Steam Pressure	Engine 32″ × 28″		Peripheral Speed of Fan Wheel	Frick Standard			
	R.P.M.	Ind. H.P.		Total Vol. of Air	Total H.P. in Air	Mech. Eff.	W.G.
100	81.5	223.39	6404.01	254,560	128.35	57.5	3.2″
100	100.00	407.99	7854.00	315,996	239.00	58.5	4.2″
100	120.5	702.96	9464.07	400,394	451.11	64.1	7.15″
100	130.0	846.76	10210.20	425,608	556.63	65.7	8.3″

This test was taken with the airways sectioned off into 36 spaces and the anemometer was held for 5 seconds in each space. Six anemometers were used and the average of all the anemometers and readings were taken to get the mean velocity of the air.

The mechanical efficiency is good, but not so good as might be obtained with this fan if the mine conditions were better. The fan was designed for 400,000 cubic feet of air per minute at a 6 inch water gage. It will be observed from the table that this mine required 7.15 inches to pass 400,000 cubic feet of air per minute, which is nearly 20 per cent more pressure than was anticipated.

The equivalent orifice of this mine is large:

$$E.\ O. = .0004 \times \frac{400{,}394}{\sqrt{7.15}} = 59.75 \text{ square feet}$$

But, it would have to be 65.37 square feet to pass 400,000 cubic feet of air per minute at a 6 inch water gage.

The manometric efficiency is fair:

$$W.G. = \frac{\dfrac{25 \times 3.1416 \times 120.5^2}{60}}{32.16} \times \frac{1.2}{1000} \times 12$$

$$= 11.08 \text{ inches}$$

The theoretical water gage is 11.08 inches and the actual water gage is 7.15 inches making a manometric efficiency of 64.5 per cent.

The volumetric capacity of this fan is:

$$C = \frac{400{,}394}{\left(\dfrac{25}{2}\right)^2 \times 3.1416 \times 9 \times 120.5}$$

$$= 75.3 \text{ per cent}$$

The volumetric capacity is low. This fan is one of the old type with retreating blades. The wheel has but eight blades. This test was taken by the engineers of the H. C. Frick Coke Company.

The third of these tests is of a 20 foot fan at the Collier Mine of the H. C. Frick Coke Company. The record is as follows:

H. C. Frick Coke Company's Collier Mine
Test of Capell Reversible Steel Fan

November 26, 1908

20′ x 8′ Direct connected to two 16″ x 24″ Engines. Fan arranged for blowing.

Steam Pressure Pounds	R.P.M.	Ind. H.P.	Periphery Speed Fan Wheel	Frick Standard			
				Total Vol. Air	H.P. in Air	Mech. Eff.	Water Gage
115	71	61.91	4461.07	116,184	28.36	45.8	1.55″
115	121	246.25	7602.67	211,304	151.48	61.5	4.55″
110	143	372.80	8984.97	256,088	250.17	67.1	6.20″

This test was taken in the usual manner known as the Frick Standard, as explained above. The airways were sectioned with wires. There were four splits each taken off from the bottom of the shaft. Number one split is 56 square feet, number two is 47 square feet, number three is 58 square feet, number four is 61 square feet, making a total

Capell Fan—Collier Mine

of 222 square feet. The equivalent orifice, however, is small as may be seen from the formula:

$$E.\ O. = .0004 \times \frac{256{,}088}{\sqrt{6.2}}$$
$$= 25.61 \text{ square feet}$$

The main airways are large and are ample in area. There must be congestion in the splits a long way from the fan, or nearly all the air is being taken to the working faces through the long splits. This equivalent orifice is unusually small for such a large volume of air.

The fan was designed for 400,000 cubic feet of air per minute at a 5 inch water gage. This would require an equivalent orifice of:

$$O = .0004 \times \frac{400{,}000}{\sqrt{5}}$$
$$= 71.43 \text{ square feet}$$

The equivalent orifice of the mine was actually but 25.61 square feet which was only about 35 per cent of what was anticipated. The fan under such conditions shows very good results. If the mine had been put into the condition as anticipated with an equivalent orifice of 71.43 feet the volume of air delivered to the mine by the fan would have been greatly in excess of the 256,000 feet shown in the test and the manometric efficiency and volumetric capacity would have been largely increased. The mechanical efficiency would also have been increased as the fan wheel was too large and too wide for the volume of air the mine could take at the water gage developed by the fan. All of these efficiencies fall down owing to the small equivalent orifice.

This test was taken by the engineers of the H. C. Frick Coke Company.

The mechanical efficiency is good when considered from the manner in which the anemometer readings are taken. Center velocity readings would greatly increase the figures in this test.

The manometric efficiency is fair:

$$W.G. = \frac{\left(\frac{20 \times 3.1416 \times 143}{60}\right)^2}{32.16} \times \frac{1.2}{1000} \times 12$$

$$= 10.08 \text{ inches water gage}$$

The theoretical water gage is 10.08 inches and the actual water gage is 6.2 inches making a manometric efficiency of 61.5 per cent.

The volumetric capacity of this fan is low:

$$C = \frac{256{,}088}{\left(\frac{20}{2}\right)^2 \times 3.1416 \times 8 \times 143}$$

$$= 71 \text{ per cent}$$

This one of the old style fans with retreating blades, eight in number. At the same time that this fan was installed, it was regarded as one of the best. While its mechanical efficiency is good, the volumetric capacity is so low as to make it obsolete at the present time. It is so large for the work it can perform, that its first cost would now be prohibitive. A present day fan, to do the work this fan is doing, should be not more than 8 feet in diameter and would give better mechanical efficiency under a load of 250,000 cubic feet of air per minute at 6 inches of water gage than this 20 foot fan.

LARGE SLOW REVOLVING FANS BEING DISPLACED BY MODERN FANS

The setting alone of this 20 foot fan would at the present time, cost more than a modern fan to do the same work. The comparison of this fan with an 8.5 foot Sirocco fan and the 4 foot 9 inch Turbine fan in Chapter XVI, will show the reader why the large old fashioned fan has been displaced with a more suitable machine. The Capell fan is no longer built in America.

Questions on Chapter XV

What usually causes a fan to be termed efficient or inefficient?

What factors are used to decide the economy or efficiency of a fan?

How is the quantity of air in circulation accurately measured?

Why must quantity and pressure be read at the same time?

How is the power consumption of a fan engine, or motor determined?

What caused the fan at Ehrenfield Shaft to not perform its duty properly?

What improvements would have resulted in a more satisfactory fan at Ronco Shaft?

What is evidently the cause of the small equivalent orifice for the Collier Mine?

CHAPTER XVI

TESTS OF MODERN FANS IN ACTUAL OPERATION

By the courtesy of the American Blower Company, the following data has been obtained for a Sirocco fan. This installation is considered by them as typical of the characteristics of the Sirocco fan. The cut shows the fan to be a reversible one and gives the reader a view not only of the fan but of the corps of engineers who took the data submitted.

When tested it was exhausting. The fan is 8.5 feet in diameter and 5.66 feet wide; chain driven by a 200 horse power motor. The record of this test is as follows:

TEST OF 8.5′ X 5.66′ SIROCCO FAN*

R.P.M. Fan	Volume Air	Water Gage	H.P. in Air	Elec. H.P.	Mech. Eff.	Man. Eff.	Volumetric Capacity
220	168,500	4.3″	114	164.5	69.3%	98.5%	248%
275	219,852	6.75″	234	352	66.5%	98.5%	248%

This fan was installed to make 150,000 cubic feet of air per minute at a 4 inch water gage. It will be observed that the first reading shows the fan making 168,500 cubic feet of air per minute at 4.3 inches water gage, which shows the mine in a better condition than was anticipated. The water gage for 150,000 cubic feet per minute is actually less than 3.5 inches instead of 4 inches as was anticipated. It is always to the advantage of the power of course, if the mine can have a less resistance than is anticipated. Let us examine

---

*This test was taken by the engineers of the Monongahela River Consolidated Coal & Coke Company.

Sirocco Fan—Alice Mine

the mine. The resistance anticipated was 4 inches for 150,000 cubic feet per minute. The equivalent orifice for such resistance would be:

$$E.\,O. = .0004 \times \frac{150{,}000}{\sqrt{4}} = 28 \text{ square feet}$$

But, the equivalent orifice was actually:

$$O = .0004 \times \frac{168{,}500}{\sqrt{4.3}} = 32.40 \text{ square feet}$$

So that there was actually about 14 per cent more orifice than was anticipated which is always favorable to the power. The mine management should always bear in mind that the power changes as the cube of the speed of the air and the speed of the air changes directly as the equivalent orifice.

The mechanical efficiency is high:

$$\text{M. Eff.} = \frac{\dfrac{168{,}500 \times 4.3 \times 5.2}{33{,}000}}{164.5} = 69.3 \text{ per cent}$$

This is unit efficiency, allowing 5 per cent loss for the chain drive and 8 per cent loss for the motor. The mechanical efficiency for the fan alone would then be:

$$\text{M. Eff.} = \frac{\dfrac{168{,}500 \times 4.3 \times 5.2}{33{,}000}}{164.5 \times .92 \times .95} = 79 \text{ per cent}$$

The manometric efficiency is also high:

$$W.\,G. = \frac{\left(\dfrac{8.5 \times 3.1416 \times 220}{60}\right)^2}{32.16} \times \frac{1.2}{1000} \times 12$$

$$= 4.34 \text{ inches}$$

The ratio of 4.3 inches to 4.34 inches is 98.5 per cent.

The volumetric capacity is good:

$$C = \frac{168{,}500}{\left(\frac{8.5}{2}\right)^2 \times 3.1416 \times 5.66 \times 220}$$
$$= 248 \text{ per cent}$$

The fan is giving very good results but if the pressure were lowered by increasing the equivalent orifice of the mine still more, the volumetric capacity of the fan would increase as would the mechanical efficiency. The heading where the readings were taken was large being 98.5 square feet. The velocity 1,710 feet, is not very high for such a volume of air. The center velocity in this case is more accurate than if the velocity had been higher. In small airways, it is more essential that the airways be sectioned off where the readings are taken, than in large airways, as the center velocity in small airways is relatively higher than in large airways. This is due to greater rubbing surface in the small airways in proportion to the large airways. For example, note the rubbing surfaces to the areas in the following:

A 4 x 6 foot airway has a rubbing surface of 20 feet and an 8 x 12 foot airway has a rubbing surface of 40 feet. The area of the 4 x 6 is 24 square feet and the area of the 8 x 12 airway is 96 square feet. The proportion of rubbing surface in the two airways is two to one whereas the areas are four to one.

TEST OF 10′ x 4′ JEFFREY FAN IN OPERATION

Through the courtesy of the Jeffrey Manufacturing Company the following data has been obtained for one of the

Jeffrey Fan—Reversible

Jeffrey fans. This installation being typical of the characteristics of the fan. The cut shows the fan is intended to be a reversible fan. When tested it was blowing.

The fan is 10 feet in diameter and 4 feet wide and is belt driven by motor of 150 horse power. The record of the test is as follows:

R.P.M.	Volume Air	Water Gage	H.P. in Air	Elec. H.P.	Mech. Eff.	Man. Eff.	Vol. Capacity
43	48,000	.2″	1.5	2	73%	85	355
86	104,000	.8″	13.	18	72%	85	385
172	200,000	3.2″	100.8	135	73.9%	91.4	370

This fan was installed to make 200,000 cubic feet of air per minute at a 3 inch water gage. It will be observed that the last reading shows the fan making 200,000 cubic feet of air per minute at 3.2 inches water gage. The actual water gage is two tenths of one inch more than was anticipated which works out very closely to the estimated water gage and the fan was therefore designed to do the work it actually encountered.

The equivalent orifice of the mine is:

$$E.\ O. = .0004 \times \frac{200,000}{\sqrt{3.2}} = 44.44 \text{ square feet}$$

It is unusually large for such a volume of air.

The fan was designed for 200,000 cubic feet of air per minute at a 3 inch water gage so that the equivalent orifice was what was anticipated and need not be changed.

The mechanical efficiency of the unit shows when the fan is running at 172 R.P.M.:

$$\text{M. Eff.} = \frac{\dfrac{200,000 \times 3.2 \times 5.2}{33,000}}{135} = 73.9 \text{ per cent}$$

The unit efficiency being 73.9 per cent, the fan alone would have a higher efficiency. Assuming the belt loss to be 10 per cent which is the usual loss allowed for belt drives and the motor running at 90 per cent efficiency, the fan taken alone would have a mechanical efficiency of:

$$\text{M. Eff.} = \frac{\dfrac{200,000 \times 3.2 \times 5.2}{33,000}}{135 \times .90 \times .90} = 92.17 \text{ per cent}$$

This record shows that the readings were not taken with care as to the volume and pressure. The efficiency of the fan is within 7.83 per cent of being a perfect machine. These errors are very apt to come in where great care is not taken in reading the instruments. The author has often had reports sent him of tests taken when the fan showed more than 100 per cent mechanical efficiency. In one case one of these records showed as high as 140 per cent mechanical efficiency. These results are often obtained from careless reading of the anemometer in the center of the air way or at one side where the velocity is the highest. Sometimes the observer hunts the place in the air way where the velocity is high and neglects to read where it is low and take the mean. These readings often times lead to absurd conclusions. Sometimes the water gage is placed immediately in front of the cut-off where the pressure fluctuates greatly and the highest point of fluctuation taken as the true reading. This is erroneous and sometimes leads to erroneous conclusions.

The data taken however, was obtained by the Jeffrey Manufacturing Company's own engineers, who ought to be familiar with the correct methods of taking such readings.

The manometric efficiency is good:

$$W.G. = \left(\frac{\frac{10 \times 3.1416 \times 172^2}{60}}{32.16} \right) = \frac{1.2}{1000} \times 12$$
$$= 3.49 \text{ inches}$$

The ratio of 3.2 inches is 91.4 per cent.

The volumetric capacity is good:

$$C = \frac{200{,}000}{\left(\frac{10}{2}\right)^2 \times 3.1416 \times 4 \times 172}$$
$$= 370 \text{ per cent}$$

The blades in this fan are pitched forward in the direction of rotation which accounts for the large volumetric capacity.

Also the fan is working on a mine with the equivalent orifice for which it was intended.

The Cherry Tree Coal Company at Emeigh Run, Pennsylvania, have a mine in a thin seam of coal which requires the taking down of the roof to obtain the area required for the ventilating current. This makes the air ways very rough and causes great friction to the current. The test of the fan ventilating this mine is given below. The reader will note that the mean velocity is obtained by four readings, each taken near the corners of the air way and no center velocity is read. These readings must be nearly accurate and should show a mean speed in the air that is not nearly so great as the center velocity would be.

This test shows very high mechanical efficiency, 77 per cent, although the equivalent orifice is small:

$$E.\,O. = .0004 \times \frac{116{,}000}{\sqrt{5.4}} = 19.97 \text{ square feet}$$

The fan is also small 4 feet 9 inches diameter of wheel so that the fan suits the condition of the mine.

The manometric efficiency is:

$$E = \frac{\dfrac{(4.75 \times 3.1416 \times 580)^2}{60}}{32.16} \times \frac{1.2}{1000} \times 12 = 9.28 \text{ inches}$$

The theoretical water gage is 9.28 inches and the actual water gage is 5.4 inches. The manometric efficiency is therefore 58 per cent.

The volumetric capacity is:

$$C = \frac{116{,}000}{\left(\dfrac{4.75}{2}\right)^2 \times 3.1416 \times 3 \times 580} = 405 \text{ per cent}$$

These various tests show that the fan is working efficiently or inefficiently in accordance with their suitability or unsuitability to the conditions of the mine. All these fans would work with nearly the same mechanical efficiency if the fans were suited to the conditions of the mine they were ventilating.

This test was taken by the engineers of the Cherry Tree Coal Company.

FAN, WHEN PROPERLY DESIGNED GIVES GREATER EFFICIENCIES

It will be observed from the foregoing records of fans that it is essential that a large equivalent orifice must be obtained if the power consumed to propel the air shall be kept down to a reasonable figure. It will also be observed that the fan is efficient if it is operating on the mine conditions for which it is designed and if the mine conditions are not what the fan is designed for, the efficiency falls off to such an extent that it does not pay to operate a fan on a mine for which it is not adapted. When the power is purchased through a meter, the record obtained is so conclusive that there can be no argument about the advisability of changing the mine so as to get a larger equivalent orifice if the mine conditions will warrant it.

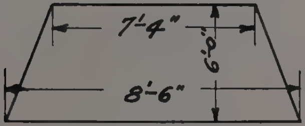
WHY INCREASING EQUIVALENT ORIFICE WILL FREQUENTLY LOWER MECHANICAL EFFICIENCY

The most of the records just analyzed, the equivalent orifice of the mine is comparatively large, as large as was necessary for a large fan. In the last one the 4 foot 9 inch fan of the Cherry Tree Coal Company, the equivalent orifice is very

Robinson Fan—Cherry Tree Coal Company

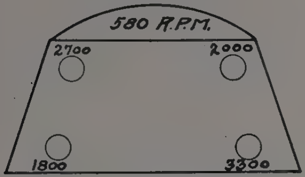
Cherry Tree Coal Company,
St. Benedict, Pa.

Fan 4′–9″ Robinson Turbine, Direct connected to 150 H.P. Motor
Data V-17 Robinson Fan—7-19-20
Checked —7-25-20



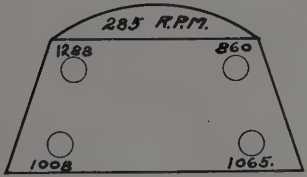
#1

48.146 square feet.



#2

2450 ft. per minute (Velocity)
116,000 cu. ft. per minute
(Note—5.4″ W. G.) (98.4 H. P. in air)



#3

1055 ft. per minute (Velocity)
51787 cu. ft. per minute
(Note—1.5″ W. G.) (12.54 H. P. in air)

No. 2—With recording Watt meter showed 95 K.W. or 127.345 H.P. or 77.18% efficiency over all.—(Note—580 R.P.M.)

No. 2—2000 Volts—54 Amps.

Assuming 80 per cent power factor—160 H.P. or 61.5% efficiency over all (Note—580 R.P.M.)

No. 3—2290 Volts—11 Amps.

Assuming 80 per cent power factor—26.89 H.P. or .465 efficiency over all.

small. The mechanical efficiency is, however, very high. This is because the fan is designed for such a mine with a small equivalent orifice. If this fan should be changed to a mine having a much larger equivalent orifice, its mechanical efficiency would fall off in proportion to the enlargement of the equivalent orifice.

If one of the large fans such as the Ronco fan or the Capell at the Collier Mine were installed at the Cherry Tree Coal Company's mine, with equivalent orifice of 19.97 square feet, its mechanical efficiency would approach zero so rapidly that no sane management would consider maintaining such a fan in operation. Yet on the mines they are ventilating their work is excellent.

It will be observed by comparison of the above tests that the manometric efficiency is a minor consideration. The mechanical efficiency is the primary factor. If it is high the manometric efficiency may be neglected.

The volumetric capacity is of primary importance when the fan is to be installed as high volumetric capacity means a small fan and low first cost, but this should never be the determining factor in the installation of the fan for if it is wasteful of power the first cost is soon wiped out in the operating expense. The mechanical efficiency is therefore, of first importance.

Questions on Chapter XVI

How may the volumetric capacity and the manometric efficiency be increased?

What is the reason for low power consumption in the case of the Sirocco fan?

What is the probable cause for the mechanical efficiency of the Jeffrey fan being abnormally high?

What is one reason for the high volumetric ratio of the Jeffrey fan?

How do you account for the high mechanical efficiency of the Cherry Tree fan?

Then do you believe that each mine has peculiar physical conditions which must be considered when specifying a fan?

By what means do we obtain high efficiencies at comparatively low power cost?

When will enlarging the equivalent orifice lower the mechanical efficiency?

CHAPTER XVII

PHYSICAL CONDITIONS ESTABLISH WATER GAGE

The number one mine of the Springfield Coal Company at Nant-Y-Glo, Pennsylvania, is a shaft mine. It develops considerable inflammable gas. It requires abundance of air to dilute the gases. It had been developed at a time when little attention was paid to ventilation and consequently the workings about the ventilation shaft bottom were choked and there was not sufficient area to pass the required amount of air. To this must be added the narrow airways that have been driven for miles into the coal and in places through the rock faults. The airway was carried in a single current which made the pressure very high for the amount of air that was passing through the mine.

INVESTIGATION OF SPRINGFIELD MINE AND RESULTS

In the year of 1914 the author was called upon to investigate the mine with the view to making the ventilation better. The examination showed about 45,000 cubic feet of air per minute passing at 3½ inches water gage. It was desired to pass a 100,000 cubic feet per minute. With the mine in the condition observed at the time the water gage for 100,000 cubic feet per minute would be as $100{,}000^2 : 45{,}000^2 :: x : 3.5$

$$\frac{X}{3.5} = \frac{100{,}000^2}{45{,}000^2} = 17.28 \text{ inches}$$

100,000 cubic feet of air per minute at 17.28 inches water gage was not at all practical. The author's advice was to put the mine in a condition to get 100,000 cubic feet at 6 inches water gage. This would require a large amount of work on the airways. The making of splits and overcasts. The drawing of water from some of the airways and the driving of some headings to make short circuits of some of the air instead of passing the air around some very bad angles. The enlargement of one of the air shafts was also a necessary step.

THE IMPOSSIBLE COULD NOT BE OVERCOME BY FAN

Through some advice, the management was persuaded to install a fan to make 100,000 cubic feet of air per minute against a 4 inch water gage. The management made the installation, thinking the fan could pass the 100,000 cubic feet per minute through the mine at a 4 inch water gage with the mine in its present condition, not knowing that the mine conditions determined the water gage.

After the installation of the new fan, the management learned that it was the mine that determined the water gage and that the fan was only a machine to create a pressure. The fan installed was of the latest type, but, it was incapable of producing more than half the required amount of air.

In the year 1916 this mine was sold to the Rembrandt Peale interests. They immediately took steps to ventilate the mine. The equivalent orifice of this mine was at that time:

$$E.\,O. = .0004 \times \frac{45{,}000}{\sqrt{3.5}} = 9.62 \text{ square feet}$$

It is obvious that this orifice must be enlarged to get 100,000 cubic feet per minute through it at a 6 inch water gage:

$$E.\ O. = .0004 \times \frac{100{,}000}{\sqrt{6}} = 16.39 \text{ square feet}$$

HOW TO GET THE 100,000 CUBIC FEET AT 6 INCHES WATER GAGE

The orifice must be nearly doubled. The new management went over the mine and found where the obstructions could be removed and the various airways enlarged and changed, new overcasts made, new splits arranged and the mine so changed that the equivalent orifice could be changed and enlarged so that it would be possible to pass 100,000 cubic feet of air per minute at a 6 inch water gage. The author was thereupon ordered to place a fan to do this work. The fan to be direct connected to a motor running with power at 2,200 Volts. The motor speed to be 580 r.p.m. and the fan being direct connected must have the same speed. The fan furnished was 4 foot 9 inches diameter and 3 feet wide. The motor was two speed pole changing, 580 r.p.m. at full speed and 290 at half speed.

R. P. M. OF FAN WILL NOT ALWAYS CREATE VENTILATION

When this fan was first put on the mine, the airways were in much the same condition as they had been, so that the new fan could not perform its full duty. At full speed of 580 r.p.m. it, at first, produced 68,000 cubic feet per minute at 4.25 inches water gage. The airways were being gradually enlarged and cleaned and certain new splits were put into operation. With these improvements, the next reading showed 88,000 cubic feet of air per minute with 5.25 inches water gage, while the fan was at full speed. The improvements in the airways were carried on still further and a third reading showed 102,000 cubic feet per minute at a 5.75 inches water gage which brought the equivalent orifice to a better condition than was expected when the second fan installation was made. The last record showed the following:

INCREASING E. O. INCREASES VOLUME AND DECREASES REQUIRED POWER

127,500 cubic feet per minute at 4.8 inches water gage. The power as read on the motor was 132 horse power, this being the total input of current.

Now, let us examine this mine and the power applied to its ventilation.

We found the equivalent orifice of the mine to be originally 9.62 square feet. Through the various means taken to enlarge this orifice, cleaning up airways and draining off water, making numerous splits and short circuiting parts of the air, the equivalent orifice had been gradually enlarged.

The latest reading showed:

$$O = .0004 \times \frac{127{,}500}{\sqrt{4.8}} = 23.29 \text{ square feet}$$

To pass 100,000 cubic feet per minute required an equivalent orifice of 16.39 square feet. The equivalent orifice of the mine had been actually increased to 23.29 square feet or nearly fifty per cent more than was expected. The result showed on the water gage and on the quantity of air passing.

Robinson Reversible Fan—Springfield No. 1 Mine

The water gage for 100,000 cubic feet per minute would now be:

$$127{,}500^2 : 100{,}000^2 :: 4.8 : X = 3.14 \text{ inches}$$

Not much more than half what was expected. It is obvious that the air is now passing with greatly reduced pressure. We would therefore, expect that the power would be reduced proportionately. We have seen above that the horse power required to pass 127,500 cubic feet per minute at 4.8 inches water gage was 132 horse power.

What is the mechanical efficiency of this unit?

$$\text{M. Eff.} = \frac{\dfrac{127{,}500 \times 4.8 \times 5.2}{33{,}000}}{132}$$

$$= 73.06 \text{ per cent}$$

On another fan of the same size and driven in the same manner we found the mechanical efficiency of the unit was 77 per cent. Why does the fan under consideration, show less efficiency than the other? It is because the equivalent orifice of the mine now under consideration has been enlarged beyond the orifice of passage of the fan and the fan must make a higher water gage or pressure to pass the air through itself than it required to pass the air through the mine.

This mine should have a larger fan to get the best mechanical efficiency, but the saving would not be sufficient to justify such changes as would be necessary to get the desired results. Should a larger quantity of air be required, then such saving might justify changing the installation, but as long as the unit efficiency is above 70 per cent, it is difficult to improve it.

This mine is one of the best illustrations of how intelligent management can make over a mine that seems too difficult to ventilate properly, and make it safe and sanitary. When the present management took over this mine, it was in so bad a condition that every man entering it, was in danger of losing his life. Now, it is as safe as a mine can be.

PROBLEMS AT FEDERAL MINE AT GRANT TOWN, W. VA.

In the year 1910 the author was called upon to investigate the ventilation of the mine of the Federal Coal & Coke Company, at Grant Town, West Virginia.

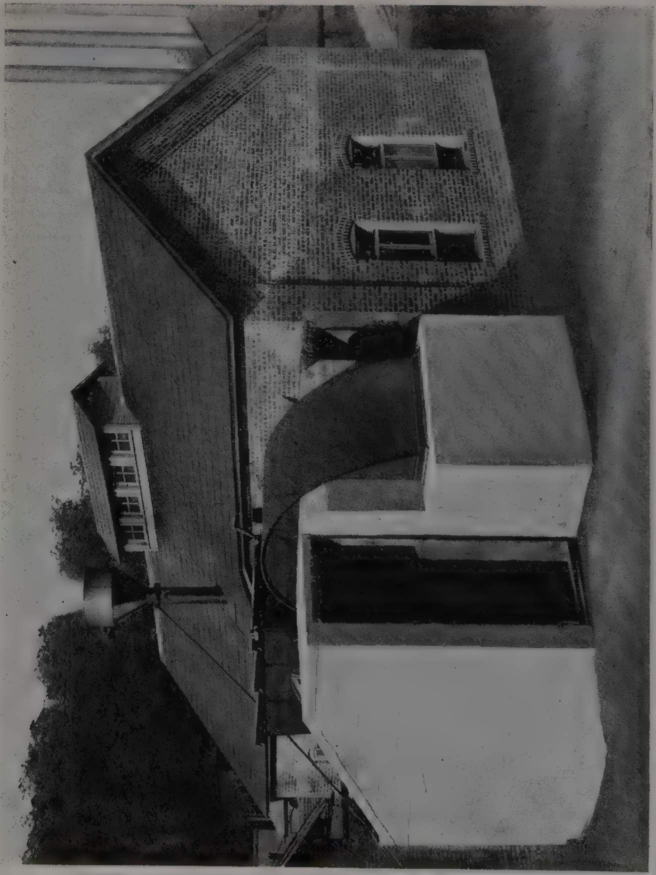
This was a shaft mine with a hoisting shaft about 300 feet from the ventilating shaft. One side was used for ventilation and the other side for auxiliary hoisting to raise and lower men. There was a wooden partition separating the two compartments. The seam of coal being worked was the Pittsburgh seam which was about 9 feet thick. The coal was about 270 feet from the surface, with the surrounding hills from 3 to 4 hundred feet higher.

A FAN NOT SUITABLE FOR PHYSICAL CONDITIONS

The ventilation was furnished by a Capell fan, 16 feet in diameter and 6 feet wide, direct driven by a steam engine. This fan was designed for a capacity of 300,000 cubic feet per minute at a 4 inch water gage. It was quite capable of performing this work. Owing, however, to the pillars which were left to support the airways being of inadequate size to support the greater weight of cover, the airways were partially closed by a squeeze. The reduced size of the airways increased the resistance to the passage of the air current to such an extent that the fan was able to force through the mine only 132,000 cubic feet of air per minute at 2.3 inch water gage. Under this duty the fan was rapidly going to pieces. It was maintained in running condition with the greatest difficulty.

The management desired the volume of air to be greatly increased as the mine was in a dangerous condition through insufficient ventilation. It was desired to pass 300,000 cubic feet of air per minute through the mine constantly. To do this under the existing conditions required 11.87 inches water gage which would require 560 horse power in the air and 800 horse power in the engine. This amount of power for the mine under the existing conditions was impractical. It was necessary to reduce the pressure. The management found a way to cut in an airway and make an extra split close to the shaft bottom, and through this an air current could be passed to reduce the pressure about 25 per cent.

The result of the calculation was that 300,000 cubic feet of air could be passed under the changed conditions at a 9 inch water gage. A turbine fan was designed for this work and a Corliss engine of 600 horse power was installed with the fan. The engine was belted to the fan, as the fan was required to run at 375 R. P. M. to produce the required pressure, and the engine was limited to 110 R. P. M. While the fan and the engine were being manufactured and installed, the airways were put in the best shape possible and when the fan was in operation, the measurement of air at the bottom of the shaft showed 288,000 cubic feet per minute at 7.5 inches water gage. There was a large leakage at the top of the shaft and in the partition between the man hoist-



Robinson Fan—Federal Mine

ing and the ventilating compartment which could not be measured. This leakage probably amounted to twenty or thirty thousand cubic feet per minute. The result showed the work done within the mine had reduced the pressure somewhat better than had been expected. It gave hopes of still further reducing the pressure with the future work that was planned.

For several years this fan furnished 185,000 cubic feet of air per minute at a 4 inch water gage. With the increased development a much larger volume was required and the volume was increased to 260,000 cubic feet per minute at a 5 inch water gage, and through further development 280,000 cubic feet per minute at 5.2 inches water gage. While operating on this condition a shaft was sunk at the back of the mine which short circuited a large quantity of air and reduced the resistance to such an extent that the mine is now operating with 240,000 cubic feet of air per minute at 2.8 inches water gage. The map attached will show the workings with the various air courses and the splits into which the air current is divided. The map is well worth the reader's attention. It is the map of a mine that is one of the most difficult to ventilate but owing to the great care and attention given to the ventilation by the management, this mine is one of the safest and most healthful.

The air is measured every twelve hours. The mine is naturally very dusty and therefore, requires great care to keep it damp. It is very gaseous and requires a large volume of air to dilute the gases. The following quotation from a description of the process used by the management to keep the mine safe, will give the reader the best idea of the assistance the ventilation needs in such a mine:

KEEPING FEDERAL MINE IN A SAFE CONDITION

"The mine is ventilated by an eight by four Robinson fan, belt driven by a forty-eight inch belt; speed of fan 360 R.P.M., driven by a 600 H.P. Hamilton engine. The amount of air produced is 240,000 cubic feet per minute against 2.8 inches water gage. This volume of air is divided into eleven different splits,—splits ranging from fifteen to thirty-five thousand cubic feet per minute.

"We have three air shafts, hoisting shaft, man shaft, and shaft at number 30 west of 7 south. The system of humidifying our mine air is by exhaust steam turned into the mine air at the fan shaft. The water spraying system is also used. This system is confined to our haulage road, a two inch water line from the surface to number 3 north, we have small spray lines branching over this main line about every fifty feet and carrying about 110 pounds pressure. This spray is only used between 6:00 P.M. and 3:00 A.M.

"With this system we are able to keep our haulage roads in fairly good condition. We also do considerable sprinkling with our water car along our butt entries where our spray lines and exhaust steam fails to reach.

"I would estimate that with the three different systems of humidifying the air, that we put in about fifteen thousand gallons of water per twenty-four hours.

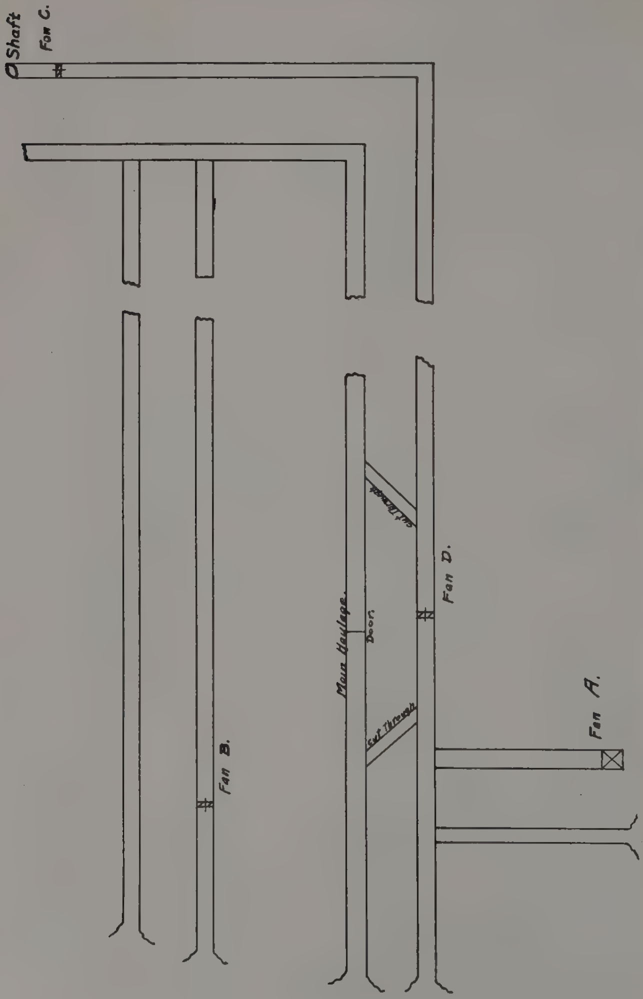
"The humidity of the mine air is taken with the regular sling Psychrometer, the same as the Bureau of Mines uses and recommends.

"*Our method of collecting gas samples:* We use a copper flask of about 1500 cubic cem. capacity: these flasks are filled with water at the laboratory and are taken into the different return splits, where both valves are opened, permitting the water to run out, which creates a vacuum in the flask; this permits the air to fill up the space made vacant by the displacement of the water: then the valves are closed and the samples taken to the laboratory and analyzed. The Hessy method is used in making the analysis; this method permits to make analysis only of CO_2 and CH_4: one man can collect and make analysis of about eight to ten samples per day."

In addition to all this care the Capell fan was put in first class condition and is kept in readiness to ventilate the mine to the extent of its capacity at such times as the primary fan might happen to be disabled. The fan is occasionally put on the mine and the primary fan stopped. This precaution is taken to insure the proper running of the secondary fan should it be needed.

A DIFFICULT MINE TO VENTILATE

In 1910 the author was called upon to inspect a mine in Ohio in the Pittsburgh Seam. This Mine had insufficient ventilation. Owing to the fragile nature of the roof, the airways were very badly choked. The management had pulled up the track in the airways so that it was difficult and expensive to keep the airways free from falls. In many places it was almost impossible to crawl over the falls of roof in the main airways. These obstructions rendered it very difficult to pass a current of air through the mine. The headings and air courses were driven to have a cross-sectional area of about 48 square feet. The current was carried through the Mine in one body without any splits and there were nearly 300 men employed within the Mine. Upon examination it was found that there were three fans at work on this mine. One, a twelve foot modern steel fan on the outside, shown at "A" in the accompanying map, and two disc-fans "B" and "C" shown within the mine. The fan on the outside was operating as a blowing fan and was direct connected to the drift mouth. The two disc fans were "boosters." Simply put in the current with the idea of assisting the air current along.



Map Showing Replacement of Three Fans by One Fan

Observations taken at the drift mouth on which the large fan was operating showed 67000 cubic feet of air per minute was passing at a 3 inch water gage. One hundred thousand cubic feet per minute was desired. The effect of the disc fans in reducing the pressure on the mine could not be determined, but the pressure was certainly reduced some by the action of the disc fans. Leaving them out of the calculation however it was evident that there would be a pressure of approximately 7 inches required to pass the 100,000 cubic feet desired for

$$67000^2 : 100000^2 : : 3'' : X$$
$$X = 6.79 \text{ inches}$$

The problem was to get the ventilation desired and do it with the least expenditure of power.

OVERCOMING DIFFICULT CONDITIONS

The mine had been so developed that a fan could be placed within the mine nearly a mile from the mouth on the main airway, so it could have two intakes and two discharges. The place selected was at "D" on the accompanying map. Cut throughs were made to connect the main haulage road and the main airway, and a door placed in the main haulage road between these cut throughs. The fan was placed within the main airway between the two cut throughs. It was driven by a 100 horse power motor. The fan was speeded to give 100,000 cubic feet of air per minute and when put in operation and measured, it was found to be making 105,000 cubic feet per minute at a 5 inch water gage.

This amount of air was more than necessary for the mine. The fan was slowed down to make 85000 cubic feet of air per minute which was found to be sufficient. The pressure of

5 inches water gage was also very hard on the doors. One man could not operate them at this pressure, but when the fan was slowed down to make 85000 cubic feet of air per minute, the water gage fell to 3.25 inches. With this pressure it was found necessary to counter-balance the doors, so that one man could operate them.

The power required to operate the three fans originally employed to make 67000 cubic feet per minute at 3 inches water gage was 176 horse power. The power required to make the 85,000 cubic feet per minute at 3.25 inches water gage with the one fan placed at "D" was 61 horse power. The volume of air was increased 18000 cubic feet and the power consumption was decreased 115 horse power. This was accomplished largely by locating the fan within the mine where it could have two intakes and two discharges, and where the leaks due to defective stopping were not working to the disadvantage of the fan. Such an arrangement as this described above would not be permitted in some of our states, owing to the law requiring the primary fan to be situated outside of the mine. Where such an arrangement serves an economical purpose, a fan should be placed on the outside, of sufficient capacity to take care of the ventilation of the mine in case of accident to the fan within the mine. Such fan being always ready for action in case of stoppage of the fan within the mine. But the fan within the mine should make the ventilation.

The power saved on this particular mine was 115 horse power after providing adequate ventilation. This power at 2 cents per kilowatt would be worth, each year,

$$115 \times .746 \times 24 \times 365 \times .02 = \$15010.41$$

This saving would provide for a fan on the outside of the mine in a very few months. It should be kept there only for emergencies.

Let us examine this mine for its equivalent orifice,

$$E.\ O. = .0004 \times \frac{100000}{\sqrt{5}} = 17.\ \text{square feet}$$

A very small orifice to pass through 100000 cubic feet of air per minute.

The equivalent orifice for the mine with the three fans operating was

$$E.\ O. = .0004 \times \frac{67000}{\sqrt{3}} = 15.48$$

It would seem that such a small difference in the equivalent orifice would not account for the great saving in power. There are other factors involved, however, the saving of the leakage of air between the main airway and the main haulage and the saving of the power applied to the disc fans being the largest factors. The disc fans were unable to create a pressure sufficient to materially effect the ventilation, and the power applied to them was practically wasted.

Questions on Chapter XVII

How do you determine the water gage for 100,000 cubic feet of air when you know the reading for 45,000 cubic feet as in case of the Springfield mine?

Can a fan manufacturer overcome the law: "the pressure, or water gage varies as the square of the quantity"?

How do you determine the equivalent orifice for 100,000 cubic feet of air at a 6 inch water gage? Solve problem.

Do the revolutions of a fan always develop the required quantity of air?

Describe methods adopted to keep the Federal Mine in a safe and healthful condition.

What is the law in your state concerning the location of a fan inside the mine.

CHAPTER XVIII

PROPER AREA OF SHAFTS AND DRIFTS FOR EFFICIENT VENTILATION

The sinking of the ventilating shafts has been made the subject of so much guess work that it is highly important that the mining fraternity take a more scientific view of this important matter.

Before a shaft is projected for ventilation purposes, the size of it should be determined with the greatest care. This is very often neglected. The volume of air necessary to supply the mine, which must pass through the shaft should first be determined and then the water gage necessary to propel the air through the mine should be also known. The life of the workings should also be determined, that is, the number of years the volume of air required, will be passed through the shaft. The cost of the shaft per yard in depth, and the square feet in area should be known. The cost of the power per horse power hour should also be known and with these known facts the engineer can determine what size ventilation shaft will best work out the property. The same reasoning will apply to drifts, with this exception that it is usually very easy to enlarge a drift if necessary or at least, quickly take off a split near the fan.

The shaft for ventilation purposes is a fixed thing, and is very difficult to change. A change almost invariably means a new shaft.

COEFFICIENT OF FRICTION FOR VENTILATING SHAFTS

The first thing to be determined is the volume of air and the pressure necessary to propel the air through the shaft.

The coefficient of friction for lined shafts varies somewhat with the area of the shaft but from experience, the best coefficient the author has been able to obtain of shafts approximately 100 square feet cross sectional area is .000000007 with this coefficient the pressure required to propel a certain quantity of air through a shaft can be obtained close enough for practical purposes. Let us take an example and discuss it with a view to establish a certain size shaft for a given property. For the sake of easy figuring, let us assume that the shaft must pass 200,000 cubic feet of air per minute and that it shall be 10 feet by 12 feet and 500 feet deep. What will be the water gage necessary to propel the 200,000 cubic feet through such a shaft? We must go back to our formula ksv^2. The k or coefficient of friction is .000000007. The rubbing surface in the shaft is 22,000 square feet and the velocity of the air in the shaft is 1666 feet, the formula then becomes:

$$i = \frac{.000000007 \times 22{,}000 \times 1666^2}{120 \times 5.2} = .68 \text{ in. water gage}$$

That is, .68 inches water gage will be required to pass 200,000 cubic feet of air per minute through a shaft 10 feet by 12 feet and 500 feet deep.

Now, let us assume that the shaft be made 8 feet by 10 feet and the same depth. Our formula then becomes:

$$i = \frac{.000000007 \times 18{,}000 \times 2500^2}{80 \times 5.2} = 1.89 \text{ inches } W.\ G.$$

Through a shaft 500 feet deep and 80 square feet cross sectional area, a pressure of 1.89 inches of water gage will be required to propel 200,000 cubic feet of air per minute.

A COMPARISON OF POWER COSTS

Let us compare these two shafts as to power consumption and see what the cost per year will be for each. The first example will appear in the formula for power as follows:

$$H.\ P. = \frac{200{,}000 \times .68 \times 5.2}{33{,}000} = 21.43 \text{ horse power}$$

That is the power in the ventilating current in the shaft is 21.43 horse power and assuming that this is 70 per cent of the power applied to the motor and that the power is costing two cents per kilowatt hour, we then have:

$$\text{Cost per kilowatt hour} = \frac{21.43}{.70 \times .746} \times .02 = .82$$

For the second shaft we have:

$$H.\ P. = \frac{200{,}000 \times 1.89 \times 5.2}{33{,}000} = 59.56 \text{ horse power}$$

With the same condition as above we have:

$$\text{Cost per kilowatt hour} = \frac{59.56}{.70 \times .746} \times .02 = \$2.28$$

For the first shaft, cost per hour is \$.82. For one year the cost would be 365 × 24 × .82 = \$7183.20. For the second shaft the cost per hour is \$2.28. For one year the cost would be 365 × 24 × \$2.28 = \$19,972.80. A difference of \$12,789.60 in favor of the large shaft. If the life of the workings at the shaft were 30 years, the saving in cost of power in that time would be \$383,688.00. The difference in the cost of the large shaft over the small one with the interest charges necessary to amortize the additional cost in 30 years would have to be computed and deducted from the apparent saving of $383,688.00, the balance would be the net gain.

The author is indebted to Mr. M. H. Hall, Chief Engineer of the Carter Coal Company of Coalwood, West Virginia, for the table on page 200 illustrating the principle just discussed.

This table will show at a glance the relative cost of shafts of different cross sectional area and the saving in power resulting from the large shafts over the small ones.

The table is prepared from local conditions as to cost per foot, and will not hold good in other localities in all its details. It is, however, a very valuable guide to the cost and relative saving of power in any locality, if the local conditions are applied to the table.

EXAMPLE OF INADEQUATE SHAFT MISLEADING ENGINEERS

The author had occasion to investigate a ventilating shaft that had been sunk without proper care or advice, which was taking a very large amount of power to pass the air down the shaft. This shaft was the subject of much controversy among the officials of the company owning the property. Some thought it sufficiently large and could be used economically. Others knew that it was too small, but were unable to prove their contention.

The shaft was 700 feet deep and was 7.75 feet by 10 feet, the area being nearly 78 square feet. It was found upon examination that to pass the desired quantity of air (225,000 cubic feet per minute) down this shaft alone without considering the mine, a 3.6 inches water gage pressure was required. The air and the water gage were read at the top and bottom of the shaft simultaneously by two sets of

Table for Determination of Economic Size for Air Shafts

Following costs are assumed
Excavation $15.00 per cu. yd.
Concrete Lining $30.00 per cu. yd.

Power at $0.02 per K.W. Hr.
Life of Mine, 50 Years

Depth of Shaft = 100′.
Sinking and Ventilating
Costs vary as Depth Approx.

Size of Shaft	Sinking or First Cost	67. Int. and 50yr. 67. Sinking Fund	100,000 Cu. Ft. per Minute		200,000 Cu. Ft. per Minute		300,000 Cu. Ft. per Minute		400,000 Cu. Ft. per Minute		500,000 Cu. Ft. per Minute		600,000 Cu. Ft. per Minute	
			Power Cost Year	Total Cost Year	Power Cost Year	Total Cost Year	Power Cost Year	Total Cost Year	Power Cost Year	Total Cost Year	Power Cost Year	Total Cost Year	Power Cost Year	Total Cost Year
6x6	$ 6,600	$ 423	$3,050	$3,473	$24,400	$24,823	$82,300	$82,723	$196,000	$196,423	$382,000	$382,423	$658,000	$658,423
8x8	9,400	596	722	1,318	5,760	6,356	19,400	19,996	46,200	46,796	90,200	90,796	155,000	155,596
10x10	12,860	816	237	1,053	1,895	2,711	6,400	7,216	15,200	16,016	29,600	30,416	51,200	52,016
12x12	16,570	1,051	95	1,146	762	1,813	2,570	3,621	6,100	7,151	11,900	12,951	20,600	21,651
14x14	20,870	1,326	44	1,370	352	1,678	1,188	2,514	2,820	4,146	5,500	6,826	9,500	10,826
16x16	25,550	1,620	23	1,643	181	1,801	610	2,230	1,450	3,070	2,820	4,440	4,880	6,500
18x18	30,650	1,996	12.50	1,958	100	2,046	337	2,283	800	2,746	1,560	3,506	2,700	4,646
20x20	36,220	2,300	7.40	2,307	59	2,359	200	2,500	474	2,774	925	3,225	1,600	3,900
22x22	42,220	2,680	4.60	2,685	37	2,717	124	2,804	294	2,974	575	3,255	992	3,672
24x24	48,700	3,080	2.98	3,083	24	3,104	80	3,160	191	3,271	372	3,452	643	3,723
26x26	55,470	3,520	1.98	3,522	16	3,536	53	3,573	127	3,647	248	3,768	428	3,948
28x28	62,860	3,980	1.37	3,981	11	3,991	37	4,017	88	4,068	171	4,151	294	4,274
30x30	70,700	4,480	.97	4,481	8	4,488	26	4,506	62	4,542	121	4,601	210	4,690

Note: Economic Size for given volume is just above broken line under Vol. heading. 100,000 cu. ft. per min. requires a 10′x10′ air shaft. 400,000 cu. ft. per min. requires an 18′x18′ air shaft.

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instruments and all possible errors accounted for. The results showed a coefficient of friction for the shaft of .000000007. Substituting the above figure in the ksv^2 formula we have:

$$i = \frac{.000000007 \times 24850 \times (2884)^2}{78 \times 5.2} = 3.6 \text{ inches}$$

The power required to pass the air down this shaft alone would therefore be:

$$H.\ P. = \frac{225{,}000 \times 3.6 \times 5.2}{33{,}000} = 124 \text{ horse power or}$$

92.5 kilowatts. This amount of power at two cents per kilowatt hour would cost in one year:

$$365 \times 24 \times 92.5 \times .02 = \$16{,}206.00$$

This expenditure for power on the shaft alone was too great and necessitated the sinking of a new shaft. The new shaft is 180 square feet cross sectional area. It is 12 feet by 15 feet. Let us see what power will be required to propel the 225,000 cubic feet per minute down the shaft and what will be the saving in money over the small shaft.

The water gage in the new shaft will be:

$$i = \frac{.000000007 \times 37800 \times 1250^2}{180 \times 5.2} = .33 \text{ inches}$$

The power required to pass the air down the new shaft would therefore be:

$$H.\ P. = \frac{225{,}000 \times .33 \times 5.2}{33{,}000} = 11.7 \text{ horse power or}$$

8.73 kilowatts. This amount of power at two cents per kilowatt hour would cost in one year

$$365 \times 24 \times 8.73 \times .02 = \$1529.50$$

The first shaft cost per year for power \$16,206.00. The saving would therefore be \$14,676.50 per year. The life of this mine will be approximately 40 years; so if the cost of power during that period should average two cents per kilowatt hour, the saving in favor of the new shaft would be:

$$\$14,676.50 \times 40 = \$587,060.00$$

The cost of sinking the new shaft together with interest charges would have to be deducted from this amount.

The reader will see from some actual examples like the above, the necessity of careful observations and the application of scientific knowledge to such problems.

The old rule of thumb in such matters will not do. Nor will ignorance backed up by large financial resources accomplish desired results.

EXAMPLE OF CALCULATION FOR A DRIFT MINE

Drift mines should have the same reasoning applied to fan drifts as we have applied to the air shaft. Mine managers overlook the importance of the fan drift. We frequently find fan drifts several thousand feet long before a split is taken off and the area of the fan drift less than 50 square feet, when a 100,000 cubic feet of air per minute is expected from the fan.

Let us examine such a condition by the use of an example:

A drift mine is passing 60,000 cubic feet of air per minute through a drift that is 2,000 feet long to the first split and is 6 feet high and 8 feet wide. What pressure will be required to pass this quantity and what power will be required? We can determine the pressure from the ksv^2 formula:

$$i=\frac{.00000001 \times 56{,}000 \times 1{,}562{,}500}{48 \times 5.2}=3.5 \text{ inches } W.G.$$

The power required to pass 60,000 cubic feet of air per minute at 3.5 inches water gage will be:

$$H.\ P.=\frac{60{,}000 \times 3.5 \times 5.2}{\frac{33{,}000}{.70}}=47.2 \text{ horse power}$$

ADDITIONAL SPLIT REDUCES POWER CONSUMPTION

The electric power applied to the motor will be 47.2 horse power. Suppose we take off a split immediately in front of the fan so that we have two air ways 2000 feet long each. What will the water gage be and the power required?

The water gage will be:

$$i=\frac{.00000001 \times 112{,}000 \times 390{,}625}{48 \times 5.2}=1.75 \text{ in. } W.\ G.$$

The power required to pass 60,000 cubic feet per minute at 1.75 inches water gage will be:

$$H.\ P.=\frac{60{,}000 \times 1.75 \times 5.2}{\frac{33{,}000}{.70}}=31.3 \text{ horse power}$$

For the double air way the power required would be 31.3 electric horse power. The saving of the double air way over the single air way being 15.9 electric horse power or 11.92 kilowatts.

The money value of this saving for a year would be with power at two cents per kilowatt:

$$365 \times 24 \times 11.92 \times .02=\$2091.38$$

It will readily be seen how expensive of power it is to cramp the air ways. If the reader will analyze the above figures, he will see the principal factor in the loss of power is the speed of the air. In this ksv^2 formula, the factors all change in direct proportion except the velocity of the air. The pressure changes as the square of the velocity. Hence, this factor is so important.

Questions on Chapter XVIII

What is the first requirement to determine before projecting a ventilating shaft?

What other information is necessary to properly construct the shaft?

What coefficient of friction is used in shaft computations?

What formulae is used to calculate the resistance of a shaft?

What is the difference in power cost for one year, when passing 200,000 cubic feet of air through a 10x12 or an 8x10 foot shaft, and why?

Does it pay to sink a new shaft for ventilating a mine, and when?

What may be done in a drift to reduce the power consumed in ventilation?

CHAPTER XIX

MINE FIRES

All coal mines are likely to have a mine fire. Whatever precautions are taken to prevent fires, they will at some time fail. Many fields of coal have been worked out without a mine fire, but it is not on account of good management. Good fortune also played a part.

Mine fires originate in a variety of ways. Sometimes from an explosion of gas or coal dust. Sometimes from a blownout shot. Sometimes from a match or other small flame falling into some inflammable material that should not be allowed to lie around in the mine. Sometimes the mine is set on fire deliberately by some malicious person.

There are so many causes for a mine fire, that all mines should be equipped to fight the fire when discovered. Delay is extremely dangerous as the whole vein of coal is a highly inflammable substance, and when it is once thoroughly afire, it is very difficult to fight. A fire on the surface or in a big city, is easy to control when compared to a fire within a mine. The apparatus that can be used on the surface cannot be used underground except some of the small apparatus which cuts a very little figure in a mine fire. The mine fires that originate from explosions are usually very difficult to fight as the mine is so badly damaged that the ventilation is uncertain at first, and until the stoppings are carefully examined and the ventilation assured, it is very dangerous for the miner to go near the fire without some approved breathing apparatus. This apparatus, of whatever character or nature, should be thoroughly tested before the miner should attempt to use it underground.

A mine fire that originates from an explosion of gas or a blownout shot is usually at the working faces and is more readily sealed off than if the mine has been set on fire in one of the main headings by carelessness or malice. It is easier to fight the fire where it can be isolated at the working faces than if the main headings were on fire. The methods adopted in any case, must be applied quickly by the local management. It takes much ingenuity to fight a mine fire and while it lasts there is nothing so harassing to the management as a mine fire.

PRECAUTIONS TO USE IN FIGHTING MINE FIRES

In the first place, those whose duty it is to fight the fire must be thoroughly familiar with the workings in which the fire is burning. Any carelessness in moving about the workings, so as to get away from the ventilation is very dangerous. The firemen must watch at all times to keep within the ventilation current, except at such times as he is exploring with the breathing apparatus or setting up brattices to conduct or control the air. Even with the breathing apparatus, he must not stay more than an hour away from the ventilating current.

It is customary for those who fight the fire, whom we shall call the firemen, to follow the fresh air current when entering the mine, and keep in the fresh air until he comes to the fire or as near it as he can find fresh air. If the brattices are down so he cannot get near the fire, as often happens after an explosion, it is essential that these brattices be built up as quickly as possible, so as to carry the fresh air to the seat of the fire, after examination, then the question of how to attack it is up to the management. A very common way is to brattice off the air from the fire with boards as quickly as possible and then erect permanent stoppings, water can be pumped until the sealed off portion is thoroughly flooded. The water is allowed to remain in the sealed off portion of the mine for sometimes six months, and sometimes even after this long period of immersion when the water is drained off a portion of the sealed place is found to still be burning. In such a case the process of sealing up the place actually burning can be repeated until the fire is extinguished.

PARTICULAR EXAMPLE OF HOW A FIRE WAS SUBDUED

The author was in a shaft mine in the state of Pennsylvania when it caught fire. The fire was discovered in a main haulage road. The fire was of incendiary origin. A carload of mine props had been pushed into a side heading and saturated with oil and then set on fire. This occurred in the afternoon when the entire mine force was at work, and the miners were all taken from the mine without loss of life. Those who were selected to fight the fire went down and placed temporary stoppings to keep the air from the fire and followed them with brick stoppings laid in cement. The portion of the mine thus sealed off from the rest of the mine was about thirteen acres in extent. It consisted largely of workings that had not been finished. The enclosure was pumped full of water and the heat generated from the fire was carefully observed. When the temperature became normal again, the sealed off portion of the mine was reopened again and the fire was found to be extinguished.

The same mine caught fire at another time when the miners were not at work. The fire got such a headway that men were unable to go down the shaft. The mine was close to a river and partly under the river bed. Bore holes were drilled at the water's edge and the river turned into the bore holes. The mine was completely flooded, nearly to the top of the shaft. After about six months pumps were installed in the shafts on cages and as the water receded down the shafts the pumps were lowered on the cages following the water as it was pumped out. When the water was all pumped from the mine, the fire was found to be entirely extinguished.

This method of putting out a fire necessitates abandoning the mine for a long period and is also very expensive. If it is possible to do so, it is better to seal the fire off by substantial brick or concrete stoppings and smother the fire. This can usually be accomplished if the fire is discovered before it gets too much headway. When the stoppings are all in place the small amount of air within the sealed area soon loses its oxygen and is converted into carbon dioxide and carbon monoxide. Both these gases are incapable of sustaining the combustion. The fire gradually dies out for the want of oxygen. Great care should be used in unsealing the fire area, for the fresh ventilation will quickly restore the flame if there is any fire still smoldering. When the fire is unsealed, apparatus for the firemen to use both to breathe with and to extinguish the flame should be at hand in abundance. A few moments with proper apparatus may be sufficient to extinguish some smoldering flame if it is taken quickly, but if the fire has a chance to get going again on a large scale through some unnecessary delay, it may require sealing off again and the whole operation gone over.

Fires are sometimes sealed off and the chemical substances used to smother the flame. If the area sealed is very large, it is difficult to use this method. If the fire is not sealed, it is dangerous to the firemen particularly if the fumes get into the ventilating current that must pass the firemen.

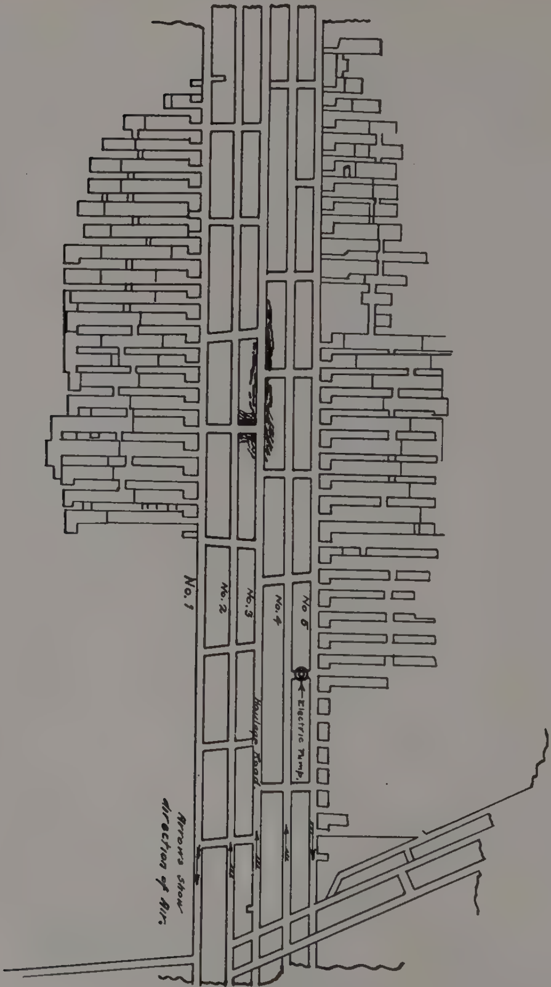
CORRECT METHOD FOR SEALING OFF A MINE FIRE

It is customary to begin sealing a mine fire by following the fresh air to as near the fire as practicable and then begin putting up stoppings in a temporary manner so as to exclude the air from the flame. The fresh air being shut off the fire smolders. It is then that the deadly carbon monoxide is generated and the firemen must use the greatest care in moving into the return current where this deadly gas is being carried from the fire. Sealing up the return air-ways requires much experience in this work, and should not be undertaken by novices. If experienced and capable men are not at hand, then the mine inspector should be sent for as promptly as possible that he may direct the work or secure men of experience to do the work for him.

Do not rely on information obtained at second hand in a case like this. The men who fight mine fires should get their experience at first hand through their finger tips.

HOW A MINE FIRE WAS IMMEDIATELY EXTINGUISHED

The following description of the manner in which a mine fire was actually extinguished in short order will no doubt be



Map of Lowber Mine

useful to those who may be unfortunate enough to have such an experience. This fire occurred in the solid coal where there were no old workings to contend with, and the firemen had the advantage of helmets, and other tools and materials that were necessary:

On November 22, 1920 about 4:00 o'clock in the morning fire was discovered in one of the headings of the Lowber Gas Coal Company's mine near Fayette City, Pa. The Pittsburgh Seam is being worked in this mine, it is about seven and one-half feet thick at this place. On receipt of the information, Mr. Wm. Bird, the mine superintendent, hastened to the scene of the fire and found it blazing and giving off smoke to such an extent that it was necessary to seal off the workings about two hundred feet from the fire. He ordered lumber, brattice cloth and other materials for stopping to be brought into the mine immediately and organized a force to put up temporary stoppings at once on the intake air courses. Reference to the accompanying map will make the description clearer. It will be noted that headings 2-3-4 are intakes and 1 and 5 are returns for the air current. Heading 3 is the haulage way. The fire originated in this heading about 300 ft. from the face. It was sealed off first with a board stopping and then headings 2 and 4 were sealed off in like manner. It was found that smoke came slowly from headings 1 and 5 after headings 2, 3 and 4 were sealed tight. This emission of smoke was no doubt caused by the expansion of the air within the imprisoned area. Headings 1 and 5 were then sealed off and all were stopped tight with cement stoppings.

In the cut through between 4 and 5 there was an electric pump which was at first put to work on the fire pumping water on it. This was discontinued however before the stoppings were built and no more water was pumped into the imprisoned area.

About a month after the fire had been sealed off an opening was made in one of the stoppings and the District Mine Inspector, Mr. Harry Phythyon and Mr. Wm. Bird, the Superintendent, made an examination. They were not satisfied that the fire was wholly quenched, so they ordered the stopping closed again and it was not opened again until January first, 1921. The fire was gone and on return of the ventilating current it did not revive. The examination showed that the fire was of incendiary origin. It had been started in headings 2 and 3, where there was no possibility of an accidental fire and no connection between the fires. These headings were new. There was no accumulation of inflammable materials where the fire originated. The fire was taken in hand promptly; within an hour after it was discovered the stoppings were being constructed and by ten p. m. of the same day the stoppings were completed and the fire effectually sealed.

The map will show how effectually these workings were sealed by stopping up the three intakes and two returns. There were no old workings to contend with, no possibility of air reaching the imprisoned area by some secret passage in the roof. There were no cave-ins to give a furnace effect to the fire in the headings.

The action of the flame burned the oxygen from the imprisoned air converting it into carbon-dioxide and carbon-monoxide, both of which would not sustain the combustion. The fire therefore died out for want of the necessary oxygen to sustain the combustion.

Where the fire had burned the ribs, the roof fell in, in both headings to a height of about six feet. This roof being thin layers of coal mixed with shale and slate burned as it fell and left the headings partially closed with ashes. The ribs were coked some but not enough to damage them as pillars.

The prompt and effective action in sealing off the airways, first the intakes and then the returns, accounts for the short time required to put out this fire. The stoppings on the intake headings were constructed without the use of helmets. The return air courses were full of smoke and vitiated air. The workmen used helmets in making these stoppings.

Questions on Chapter XIX

Name some of the common causes of mine fires.

What precaution should be used in fighting mine fires?

What is the method of procedure in fighting a mine fire?

How was a fire fought as related in this book?

Relate an incident of how a fire under your observation was fought.

How would you seal off a mine fire? State fully.

Give description of Lowber mine fire and how it was extinguished.

Which would you first seal off in case of mine fire, the intake or return and why?

CHAPTER XX

CONCLUSIONS

We have taken up this subject of ventilation from a historical point of view, we have followed it through crude beginnings to an accurate scientific solution. Have we reached the final phase? We do not know. All modern methods of conducting the arts are changing. Changing by fits and starts but nevertheless changing and growing better with these successive changes, as men give thought to their work and take a pride in it. Hoping to excel through emulation, they succeed beyond their own expectation.

This is seen through the ventilation of mines in a conspicuous degree. When the author began his work in this line in the late nineties of the nineteenth century, the most appalling and distressing accidents from mine explosions were so frequent that many thoughtless persons believed they were unavoidable—"Something unavoidable—the will of God." That was the expression of opinion of the thoughtless and the pious.

PASSING AIR THROUGH A FAN DOES NOT VENTILATE A MINE

There was a reason for these explosions and those of us that could think and act in accordance with our thoughts made haste to find a prevention for these disasters. At that time there were fans and safety lamps and about all the safety appliances we now have. Most of the disasters were happening where large fans were installed. These mines showed large volumes of air passing through the fans, but when it came to close investigation, very little air was reaching the miners at the working faces. It became necessary to investigate the working faces and see what proportion of the air made by the fan was getting to the working faces. These investigations invariably showed a small proportion of the air reached the working faces. The disasters almost invariably originated in the working places and not in the main air courses. It became necessary to make a larger proportion of the air passing through the fan reach the working faces. This meant stopping the short circuiting of the air through the numerous doors and cut-throughs. The doors were largely removed by making overcasts and the cut throughs were made tighter by permanent stoppings of brick or concrete. The effect of all this was to put back pressure on the fan increase the pressure of the mine and make the fan inefficient, make it choke itself and take the air into its wheel and cast it back again at the cut-off. This process caused many good fans to destroy themselves. What could be the remedy for this? It required some thought and experience and experimentation to find the solution.

The cause was apparent. The various tight stoppings and regulators and constricted air-ways had increased the resistance. In doing so had decreased the equivalent orifice of the mine. If the equivalent orifice of the mine could not be increased, then the obvious thing to do was to decrease the orifice of passage of the fan to accommodate the equivalent orifice of the mine.

This experimentation worked out in accordance with what was anticipated. The fan must be so designed as to suit the equivalent orifice of the mine. Getting the fresh air to the miners was not merely a matter of avoiding disasters; it was also a necessary thing for the miners' health and incidentally a question of profit for the mine owner. Mr. D. Harrington mining engineer for the United States Bureau of Mines in an admirable paper read at Duluth June 1920 makes these observations:

"It is of much greater advantage to discuss this subject along lines of efficiency with especial regard to dollars and cents rather than along lines of promotion of health and safety, but a short discussion of both features will be the object of this paper", and again "It is entirely probable that the generally accepted superior healthfulness of coal miners as compared with metal miners is very largely, if not wholly, due to the fact that most coal mines have ample supply of air circulating where men work, while the vast majority of workers at the faces in the metal mines must breathe stagnant, if not absolutely impure air." This last observation applies to the coal miners at the present time, and is due to persistent efforts of mine managers in the last quarter century to get the air to the working faces.

Mr. Harrington, in the paper above referred to, shows conclusively that it is profitable to the mine owners to get the air to the working faces that the miner may not only be healthy but be efficient in the work he has at hand and make good for the time he is employed.

Thus, we see that our efforts to remove the cause of the disastrous mine explosions has not only been very effective in that direction but has brought healthfulness to the miner and increased profit for the mine owner.

We have entered a period of rapid development of the forces of nature to the uses and abuses of man. What is in the future, we do not know. Perhaps the new development of power from sources other than coal may be the means of ending the mining of coal. Perhaps these other forms of power will be so superior to our crude methods that coal will not be needed. Coal mining will cease when such a time arrives. The coal mining industry can console itself with the thought that today it is the basis of all civilization and has been the means directly or indirectly of accomplishing nearly all the great feats of Science and the Mechanic Arts.

ADDENDA

The effect of coal dust in the ventilating current has been referred to several times in the text. The reader may desire something more definite and for such information he is referred to Bulletin No. 83—Department of the Interior, Bureau of Mines, on "The Humidity of Mine Air." The following excerpts are taken from this Bulletin:

"Experiments in the gas-and-dust gallery at the Pittsburgh testing station of the Bureau of Mines verified the fact that certain dusts that explode violently when dry are rendered inert by proper humidification of the atmosphere within the gallery, and the importance of humidity as a factor in limiting the inflammability of coal dust in a mine is demonstrated by the fact that there has never been in Illinois a dust explosion during the summer months, whereas the records show a number of dust explosions during cold weather. It is easy to see that the warm moisture-laden air that enters a mine in the summer must deposit moisture on cooling, whereas the cold and relatively dry air that enters in winter must take up moisture as it becomes heated in traveling through the mine.

INSTRUMENTS FOR MEASURING MINE HUMIDITY

A psychrometer or hygrometer is an instrument for measuring the quantity of acqueous vapor in the air. One type involves a determination of the temperature of evaporation and consists of two similar thermometers, one called the dry bulb and the other the wet bulb. A thin muslin sack is fitted over the wet-bulb thermometer, and in order to make an observation the sack is thoroughly moistened and both thermometers are placed in a current of air that has a velocity of 15 feet or more per second. If the relative humidity of the air is less than 100 per cent, some of the water on the muslin sack is evaporated, a certain amount of heat is absorbed by evaporation, and the temperature of the wet-bulb thermometer is reduced to a point at which the amount of heat absorbed by evaporation is just equal to that received from the surrounding air. From the readings of the two thermometers, by reference to suitable tables, the relative humidity and the quantity of acqueous vapor per cubic foot of the air may be determined.

There are two kinds of instruments using wet-bulb and dry-bulb thermometers for determining the relative humidity of air—the sling psychrometer and the stationary hygrometer.

The sling psychrometer is used in places where the velocity of the air is low. The instrument must be rapidly whirled through the air in order that the velocity against the wet-bulb thermometer shall approximate 15 feet per second. The standard sling psychrometer designed by the United States Weather Bureau has two thermometers mounted side by side, the wet-bulb thermometer extending below the dry bulb, which are attached by a link to a handle. By means of the handle the instrument can be whirled to obtain a velocity of the wet bulb of about 3 feet per second. This type of psychrometer is unprotected, and when it is swung in a mine it is likely to be broken by striking against the side, roof, or a timber. To guard against such breakage the Bureau of Mines has designed a special form in which the thermometers are attached to an aluminum frame, with a pivoted handle stiffly connected. Carried in a leather case with shoulder strap is a convenient instrument for mine use, and if used with ordinary care it is not liable to be broken.

The stationary hygrometer may be used in places where the air is moving at the required velocity of 15 feet or more per second. This form of instrument was used in the coöperative investigations for the underground readings at the mines. The hygrometer consists of two exposed thermometers 12 inches long, accurately calibrated and graduated to the Fahrenheit scale, and mounted on a silvered brass back which is fastened by a bent support to a wooden frame. The thermometer bulbs extend 2 inches below the mounting to allow free circulation of air around the bulbs and the stems. The wet bulb is covered with a fine muslin bag to which is attached the wicking that extends into a nickeled water cup. Water is thus brought by capillary attraction to the muslin bag. In order to protect the hygrometers from breakage, a shelter of 24-gage galvanized iron was made. It consisted of two 7-inch cylinders intersecting at right angles. To allow perfect circulation of air around the thermometer bulbs, the horizontal cylinder is open at both ends, each end being protected by a screen of hardware cloth of ¼-inch mesh. In the vertical cylinder there is a similarly protected opening to allow convenient reading of the thermometers.

A hygrograph is an instrument by which the variations in atmospheric humidity are automatically recorded. In appearance, this instrument resembles a thermograph except that an animal hair is substituted for the spiral lamina. The hair expands and contracts with changes in relative humidity, and the movement is recorded on the revolving chart with a pen.

According to the kinetic theory, gases and liquids are composed of extremely small particles, called molecules. These particles dart about in straight lines until deflected by encounters with other molecules or with the walls of the containing vessel. The average velocity of the molecules increases with the temperature.

When liquid water and water vapor are in contact some of the darting molecules of the liquid escape from the surface of the liquid and enter the vapor. Also, some of the molecules of the vapor enter the liquid. The measure of the tendency of a substance to become a gas, or vapor, is its vapor pressure. Different substances have different vapor pressures, and these differences may be shown by the fall of the mercury column in a barometer tube when a small quantity of a liquid is inserted so that its vapor can enter the space above the mercury in the tube.

If the vapor pressure of the liquid be greater than the pressure of the vapor, more molecules leave the liquid than return to it, and evaporation takes place. If the vapor pressure of the liquid be less than that of the vapor, more molecules enter the liquid than leave it, and there is condensation.

For any given temperature there is a definite vapor pressure at which the number of molecules leaving the liquid equals the number of those entering it. This state is defined as physical equilibrium and is independent of the amounts, whether relative or absolute, of either the liquid or the vapor.

To illustrate the effects of varying relative temperatures and humidity of water and water vapor in juxtaposition, the following tabulation has been prepared.

Table 1.—Effects of varying the relative temperature and humidity of water and water vapor in juxtaposition.

Temperature of Water	Temperature of Vapor	Relative Humidity of Vapor	Vapor Pressure of Water	Pressure of Vapor	Result
°F	°F	Per Cent	Inches of Mercury	Inches of Mercury	
60	30	100	0.517	0.164	Evaporation
60	60	60	.517	.310	Evaporation
60	90	85	.517	1.197	Condensation
60	80	50.6	.517	.517	Neither evaporation nor condensation

Table 2, below, gives the values of the vapor pressure of water, in inches of mercury, for temperatures ranging from 0° to 212° F.

Table 2.—Vapor pressure of water for temperatures of 0° to 212° F.*

Temperature	Vapor Pressure of Water	Temperature	Vapor Pressure of Water
°F	Inches of Mercury	°F	Inches of Mercury
0	0.0383	70	.732
10	.0631	80	1.022
20	.103	90	1.408
30	.164	100	1.916
40	.247	150	7.552
50	.360	200	23.45
60	.517	212	29.92

WEIGHT OF AIR

The weight of a volume of air varies directly with the pressure and inversely with the temperature. At a pressure of 14.7 pounds per square inch, and at a temperature of 32° F., a cubic foot of pure dry air weighs 0.080728 pound. Table 3 shows the weight of 100,000 cubic feet of pure dry air at temperatures of 0° to 100° F. and with a uniform pressure of 14.7 pounds per square inch.

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*Marvin, C.F., Psychrometric tables: U. S. Weather Bureau Bulletin 235. 1900.

MOISTURE IN AIR

Absolute humidity may be expressed as grains of water per cubic foot of air, but because of the large amounts of both air and water involved in studies of mine air it is more convenient to express absolute humidity as gallons of water per 100,000 cubic feet of air.

The amount of moisture in the form of acqueous vapor that may be present in a space occupied by air depends mainly on the temperature of the air. Table 3 gives the weight of saturated acqueous vapor in pounds and the quantity of water in gallons that will exist in a space occupied by 100,000 cubic feet of air when the relative humidity is 100 per cent and the temperature varies from 0° to 100° F.

Table 3.—Physical changes in air due to temperature*

Temperature of the Air	Weight of 100,000 cubic feet of Pure Air	Weight of Water in 100,000 Cubic Feet of Saturated Aqueous	Quantity of Water per 100,000 cubic feet of Air
°F	Pounds	Pounds	Gallons
0	8,635.4	6.9	0.823
10	8,459.4	11.1	1.329
20	8,275.5	17.6	2.114
30	8,106.3	27.6	3.312
40	7,943.9	40.7	4.878
50	7,787.9	58.2	6.979
60	7,637.9	82.1	9.843
70	7,493.5	114.0	13.686
80	7,354.6	156.2	18.776
90	7,220.6	211.3	25.439
100	7,091.4	282.4	34.058

*Relative humidity, 100 per cent; pressure, 14.7 pounds per square inch.

Table 4 gives the changes in relative humidity that accompany increases in temperature from 0° to 100° F. if the quantity of water vapor remains constant.

The interrelation of the temperature and the relative humidity of mine air is of great importance. Tables 3 and 4 indicate (a) that it is not always sufficient for mine safety to have a relative humidity of 100 per cent at the intake of a mine, because if the entering air had a low temperature the acqueous vapor present would suffice for only a low relative humidity at the return; and (b) that to insure a proper condition of the intake air both temperature and moisture must be added during the greater part of the year in order to prevent the extraction of large quantities of water from the mine by the ventilating current.

Table 4.—Changes in relative humidity due to temperature[*]

Temperature of Air	Quantity of Water per 100,000 Cubic Feet of Air	Relative Humidity	Temperature of Air	Quantity of Water per 100,000 Cubic Feet of Air	Relative Humidity
°F	Gallons	Per Cent	°F	Gallons	Per Cent
0	1.329	Super-saturated	60	1.329	14
10	1.329	100	70	1.329	10
20	1.329	63	80	1.329	8
30	1.329	40	90	1.329	7
40	1.329	27	100	1.329	6
50	1.329	19	..	.	..

[*] Quantity of water assumed to be constant.

RÉSUMÉ OF MINE-HUMIDITY INVESTIGATIONS IN—UNITED STATES

H. N. Eavenson

Eavenson, in November, 1908, prepared tables that show the average monthly weight of acqueous vapor and the average monthly temperatures in the outside atmosphere in the Appalachian coal fields.[†] He also presented the results of humidity observations in five mines in McDowell and Logan Counties, W. Va., where the quantity of air delivered by the fans ranged from 102,000 to 200,000 cubic feet per minute. He concluded from these figures that "during the winter months water is removed from the mine by the ventilating current at rates of 21 to 69 tons per 24 hours, and that in the summer months it is deposited in the same mines at rates of 12 to 23 tons in 24 hours. Can anyone doubt that the removal of such an amount of moisture from the mine air of mines apt to be dusty may convert a mine ordinarily safe into one liable to cause a terrific explosion, if anything should happen to raise the temperature to the explosion point of the dust?"

[†] Eavenson, H. N., effect of humidity on mine explosions: Trans. Am. Inst. Min. Eng. Vol. 40, 1909 pp. 835–846.

It is evident from the records and tables given that coal dust in the ventilating current is a very dangerous substance and should be taken care of by humidifying. Each mine should be a special study and should have apparatus suitable to its own conditions.

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MINING Methods 3

Practical Mine Ventilation

NAME DATE